Transformations of Iron by Bacteria in Water

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CONDITIONS in water favor the growth of many different micro-organisms. Principal among these are algae which require only mineral nutrients from the water and obtain their energy from sunlight. There are also many bacteria, as well as filamentous fungi and protozoa, that grow on organic materials and develop extensively in waters containing large amounts of organic matter. Still other bacteria can develop in water containing little or no organic matter but in which there are ferrous or manganous compounds, sulfides or certain other incompletely oxidized mineral substances which can be used by iron bacteria, sulfur bacteria or other autotrophic bacteria as sources of energy for growth. The development of algae, heterotrophic micro-organisms and autotrophic bacteria may be so profuse in water supplies that it is necessary to provide a means to prevent their growth and the formation of their objectionable products.

In developing methods of control it is desirable to establish the nature of the organisms causing the trouble and to know the characteristics and growth requirements of these organisms.

The iron bacteria, which are members of the third group, are some of the most important fouling organisms, since they not only produce troublesome accumulations of cell material but also still greater quantities of ferric hydrate. In addition to the iron bacteria there are various other bacteria, including sulfur bacteria and sulfate-reducing bacteria, which are responsible for various transformations of iron. Some bring iron into solution, others cause its precipitation and, in certain instances, the bacteria are responsible for corrosion. These reactions may be due to changes in pH, to oxidation or reduction, to production of sulfide, to differences in concentration of CO_2 or to the formation and decomposition of organic compounds of iron, all of which

can be brought about by micro-organisms. The reactions affect inorganic compounds of iron in solution or in the solid state, organic compounds, and even metallic iron.

Some of the iron transformations are brought about by bacteria having specific physiological characteristics intimately associated with the iron transformations, whereas in other cases the transformation of the iron is incidental to the normal development of the bacteria. It is important to establish the characteristics of the different bacteria in order to understand their relationships to the various changes which iron undergoes. Some of these bacteria and their actions are:

1. *Iron bacteria.* Oxidize ferrous iron to ferric iron and effect the precipitation of ferric hydrate.

2. *Non-specific bacteria.* Cause changes in the iron content of water by altering the environmental conditions.

(a) Cause changes in reaction. Increase in acidity tends to bring iron into solution while decrease in acidity tends to cause precipitation.

(b) Cause changes in the degree of oxidation and reduction. Oxidation tends to favor precipitation, whereas reduction favors solution.

(c) Produce and decompose organic compounds of iron. Organic iron compounds which are slightly ionized tend to remain in solution, but decomposition of slightly ionized organic compounds of iron leads to iron precipitation.

(d) Cause changes in the CO_2 content of water. Increase in CO_2 content tends to favor solution, large amounts of CO_2 may cause precipitation, and decrease in CO_2 content favors precipitation.

3. *Sulfur bacteria.* Some of the bacteria increase the acidity and thus tend to dissolve iron; under specific conditions insoluble iron sulfate may be produced.

4. *Sulfate-reducing bacteria.* Iron becomes precipitated by a direct reaction with sulfide which is produced by sulfate reduction. These bacteria also effect the anaerobic corrosion of iron, but by another reaction.

It is apparent that there are numerous changes of iron in which bacteria take part in addition to those which are brought about by the iron bacteria. Whereas non-specific bacteria may be associated with iron precipitation, some of them are also important as agents of solution of iron, and, as such, provide conditions favorable for subsequent precipitation which may lead to turbidity of water or fouling of pipes.

Iron Bacteria

The development of iron bacteria may manifest itself in several ways. There may be hard deposits which tend to fill up the pipes and reduce their water-carrying capacity. Slime and accumulations of filamentous bacteria may form on the walls of pipes and water holders and scum may be produced on the water surface. These bacteria may cause turbidity and discoloration of water and be responsible for some of the unpleasant tastes and odors which are produced either directly or indirectly as the dead bacterial cells are decomposed by other micro-organisms. Cases of very profuse development of the filamentous iron bacteria have been referred to as "water calamities."

Control problems have arisen with water from some deep wells (1, 3) and organic soils (8), since these waters carried considerable amounts of iron

or manganese in solution as inorganic or organic compounds. Surface waters may also cause difficulties, due to the iron content of the raw water as well as to iron which becomes dissolved from pipes and other equipment. Larson (5) reports a case where the water was iron-free upon leaving the plant but where there was as much as 8 ppm. iron at the end of the line a short distance away which gave rise to "red water." Tenny (8) reports a condition in Des Moines, Iowa, where water, collected below ground, showed an increase in iron content to more than 0.6 ppm. In the concrete gallery where the water was gathered iron bacteria formed thread-like growths coated with ferric hydrate, some of which broke loose and gave the water a red color. *Gallionella* was particularly prominent, but *Leptothrix* and *Sphaerotilus* were also encountered. Iron bacteria are believed by Carroll (3) to have been responsible for bad odor and taste of water which came from deep wells. There was a heavy deposit of soft brown material in the reservoir, and the water at the ends of the lines had a black color. Alexander (1) states that even though the water from deep wells may be free from bacteria and odors when the deposit is first tapped, bacteria and their products may appear after the deposit has been drawn upon for some time. The result is formation of slime and development of iron and sulfur bacteria in the tanks and pipes, causing the water to have an objectionable odor and taste.

The iron bacteria are typical water organisms. They are aerobic, and many of them differ morphologically from the common bacteria in that they are filamentous. They are widely distributed in nature and are found commonly in stagnant water, wells, mines,

springs and in quiet parts of streams, marshes and lagoons, as well as in reservoirs and water pipes, but seldom in open water. They are not normal inhabitants of water that does not contain an appreciable amount of iron in solution.

They are characterized by an unusual capacity for accumulating ferric hydrate around their cells, which gives them a brown to rust-red color. Manganese compounds also are oxidized by some of the iron bacteria and compounds of manganese may sometimes exceed in amount those of iron in the material precipitated by the bacteria (7, 11). It is generally assumed that the iron and manganese have played some role of importance to the cells preceding their precipitation.

The iron bacteria are fouling organisms and not agents of corrosion. It sometimes happens that the surface of the fouled metal shows evidences of corrosion, but in such cases it is probable that the corrosion was caused only indirectly by the iron bacteria.

Iron bacteria are particularly important fouling organisms since they accumulate large amounts of ferric hydrate, amounts many times greater than those of the bacterial cell material. It has been calculated that, as a result of growth of the bacteria on the ferrous iron in solution, there will be about 500 times as much precipitate of ferric hydrate as cells of the iron bacteria. This is of particular importance in establishing the cause of water troubles. It is apparent that, in cases where the iron bacteria have been the sole cause of the trouble, there will be an abundance of ferric hydrate and that the cells of the bacteria will be comparatively inconspicuous. If the fouling material consists principally of bacterial filaments and slimes with com-

paratively little ferric hydrate, the condition could not have been due to growth of the bacteria on ferrous iron to any appreciable extent. In such cases it is more likely that the bacteria had developed on the organic constituents of the water or some material other than the ferrous iron.

Some of the ferric hydrate which becomes precipitated on the walls of a pipe may come from the pipe itself and go into solution at one point only to be oxidized and deposited elsewhere. The principal source of iron in many cases, however, is the water delivered to the distribution system. This has been demonstrated where deposition has been controlled by freeing water of iron at the water works. There is further evidence in the results of Schorler (7), who found that pipes which were coated inside with asphalt became heavily incrusted with iron even though the surface of the pipe was intact and free from corrosion. Iron bacteria also develop on concrete if the water contains sufficient iron and if other conditions are favorable for their development. A case of this type was discussed by Tenny (8). Reddick and Linderman (6) concluded, however, that cement prevents tuberculation, since it both covers the metal and makes the reaction alkaline.

Further evidence that the iron need not come from the surface upon which the iron bacteria develop is provided by tests made with inert materials. In cases where iron deposition occurred, growth of iron bacteria was obtained on glass surfaces submerged in the water. In fact, microscope slides and coverslips which have been exposed in this way have been used to study the morphology of iron bacteria.

Although it is important to microbiologists to establish the mechanism of precipitation, this information is not always necessary in order to deal with the troublesome accumulation of iron deposits in water distribution systems. Nevertheless, more definite information regarding these bacteria may serve as a guide for the development of more effective control measures. The pertinent fact is that these bacteria occur in accumulations of precipitated iron and are concerned in the formation of these accumulations. Any means which can be used to prevent their development can be expected to aid in preventing fouling. Control procedures may center about the destruction of the bacteria themselves or the removal of the iron from the water before it enters the distribution system. Their ability to precipitate iron depends on the composition of the water, and particularly on the presence of iron in the water and the compounds in which it occurs.

Many conflicting ideas have been expressed concerning the iron bacteria, their physiology and their relationships to the precipitation of iron. According to some investigators they are the principal agents of iron precipitation in nature and the cause of most of the trouble resulting from iron precipitation in water works and distribution systems. Others consider that these bacteria are but one of several agents responsible for the precipitation of iron. There is similar lack of agreement regarding the means by which the iron is precipitated by the bacteria. Whereas there is widespread belief that iron bacteria are autotrophic—that is, that they live on the energy released by the oxidation of ferrous iron to ferric iron—it is contended by others that many, if not most, of the iron bacteria live on organic materials and effect the precipitation of iron incident

ally during their growth. It is probable that the iron bacteria are not all alike physiologically and that no single explanation of the precipitation of iron would be equally applicable to all of them. There is no reason to doubt, however, that there are bacteria which become coated with ferric hydrate, that these bacteria have distinctive morphological characteristics, or that their normal habitat is iron-bearing waters.

Morphology

The iron bacteria can be placed in three different morphological groups:

1. Haplobacteria, which are shaped like the common bacteria; and which occur singly or in irregular aggregates.

2. Trichobacteria or filamentous bacteria, whose filaments are composed of chains of cells enclosed in a sheath.

3. Stalked bacteria, which are oriented from top to base.

They have been classified more in detail under three orders in several different genera, the principal of which are listed below:

Order I.   Eubacteriales (true bacteria)
   Genus 1.   Siderocapsa
Order II.   Chlamydobacteriales (filamentous bacteria)
  Family 1.   Chlamydobacteriaceae
   Genus 1.   Sphaerotilus
   Genus 2.   Clonothrix
   Genus 3.   Leptothrix
   Genus 4.   Crenothrix
Order III.   Caulobacteriales (stalked bacteria)
  Family 1.   Gallionellaceae
   Genus 1.   Gallionella

Many additional genera of iron bacteria have been proposed and also numerous species of most of these genera have been described, but only a few typical species are mentioned below. [For further details see the monographs by Cholodny (13) and Dorff (15).]

Siderocapsa. These organisms are coccoid cells or short rods occurring in small colonies composed of from one to 30 cells, most frequently less than ten, surrounded by a mucoid capsule. In all colonies the outer deposit surrounding the capsule of a single colony or a group of colonies is rust-brown in color due to accumulated ferric hydrate. The cells of S. treubii are 0.6 to 1.6μ in diameter, whereas S. major is a small rod measuring 1.4 to $1.0 \times 2\mu$. The cells are readily stained by an ammonium-oxalate crystal-violet solution. Most results seem to indicate that these bacteria live on organic materials and are not autotrophic. It is possible that the occurrence and development of Siderocapsa is sometimes overlooked and their importance as fouling organisms is underestimated, since they are less readily detected than the large filamentous bacteria.

Chlamydobacteriales. Bacteria of this order are filamentous, alga-like and sheathed. Most of them are unbranched, but some show false branching. In the latter case the branches arise following displacement of the cells in the filament from which new branches are formed. Thus the sheath is branched whereas the filaments are separate. The sheath may be composed entirely of organic matter, or of organic matter impregnated with iron, or entirely of ferric hydrate. In some cases conidia and motile swarmer cells are produced.

Sphaerotilus (Cladothrix). These are colorless filaments attached at the base and showing false branching. The filaments are composed of rod-shaped or oval cells surrounded by a firm

sheath which is soft and slimy and contains no ferric hydrate. Reproduction is by non-motile conidia or motile swarmer cells. The most common species is *S. natans*. It is very widely distributed and is generally found in waters containing organic materials such as sewage or water where leaves and algae are undergoing decomposition. It has been cultivated in organic media, but its ability to live on iron compounds is questioned.

Clonothrix. These are filaments attached at the base and showing false branching. The sheath is organic and encrusted with iron. The filaments are broader at the base ($5-7\mu$) than at the tapering tips (2μ). The cells are cylindrical and reproduce by spherical conidia which are formed in chains by transverse fission. The type species, *Clonothrix fusca*, has been reported to be a common iron bacterium in water works and pipes carrying water.

Leptothrix (*Chlamydothrix*). Members of this genus consist of cylindrical cells joined in long filaments enclosed in a common sheath which is first thin and colorless and later thicker, yellow or brown, and encrusted with ferric hydrate. There is very little evidence of a sheath in the young cells, and the sheath of old cells can be almost entirely dissolved with dilute HCl, suggesting that it contains very little organic matter. When the sheath is removed with acid the inner cells are revealed. Reproduction is by cell division, fragmentation of filaments and motile cylindrical swarmer cells measuring 0.7×2 to 14μ. Some species show true branching. Most cells are not attached, whereas some are attached at the base by holdfasts. The filaments of the type species *L. ochracea* have an inner diameter of about 1μ and a sheath from 0.5 to 1μ thick. The filaments may attain a length of 1 cm. The brittle and delicate sheath enclosing the cells becomes thickened and brown as iron is deposited. The cells may creep out of old sheaths and leave behind the empty tubes of ferric hydrate. The new cells then form a new sheath. These bacteria are common inhabitants of running and stagnant iron-bearing waters and are encountered in water works. *L. ochracea* is likely to occur in pure well waters and springs which are poor in organic matter, whereas *L. crassa* is found more commonly in slow-flowing water containing some organic matter. Among the species of *Leptothrix* are facultative autotrophs. Some have been cultivated in organic media.

Crenothrix. These are unbranched filaments which are attached at the base. The cells are enclosed in a sheath composed of organic matter which is at first thin and colorless and later becomes thickened and takes on the brown color of the precipitated ferric hydrate. The cells are cylindrical to spherical, dividing in three planes to produce non-motile conidia 1 to 2μ in diameter. The type species is *C. polyspora,* which differs from other iron bacteria in that it is very large; the filaments may be several millimeters long and 2μ in diameter. The filaments expand toward the tip where conidia are released. It has been found commonly in wells and water pipes and frequently occurs together with *Gallionella*. It also grows in running water containing organic matter and iron salts and produces thick masses having a brown or green color. It has been reported to be one of the most troublesome iron bacteria in water supplies. *C. polyspora* is probably a facultative autotroph.

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FIG. 1. *Siderocapsa treubii.* Multiple colonies surrounded by ferric hydrate. Mag. about 500 ×. From Hardman and Henrici (17), Fig. 4.

FIG. 2. *Sphaerotilus dichotoma.* Sketch showing false branching. Mag. about 230 ×. From Molisch (18), Fig. 3b.
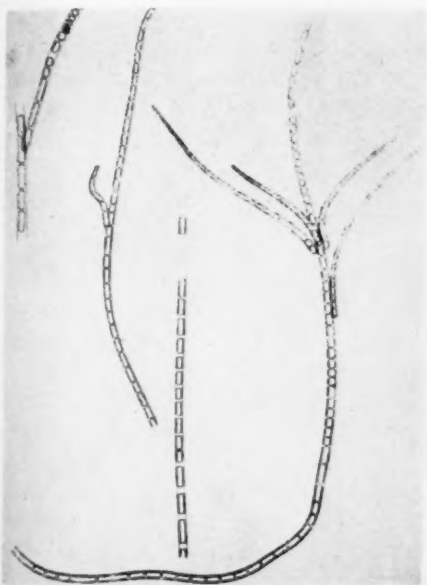
FIG. 3. *Clonothrix ferruginea.* Sketch showing cells enclosed within a sheath, and false branching. Mag. about 430 ×. From Molisch (18), Fig. 4.

FIG. 4. *Leptothrix ochracea.* Sheaths from an accumulation of precipitated ferric hydrate in iron-bearing water. Mag. about 390 ×. From Molisch (18), Fig. 5.

FIG. 5. *Leptothrix ochracea*. Cells coming out of their sheath. Mag. about 2200 ×. From Cholodny (13), Plate 4, Fig. 20.
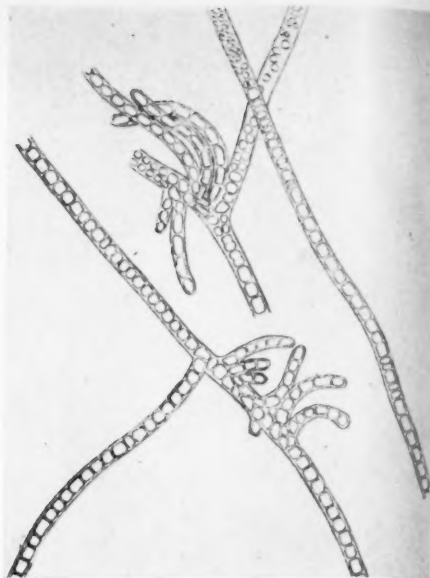
FIG. 6. *Crenothrix polyspora*. Sketch showing details of false branching of cells within the sheath. Mag. about 380 ×. From Harder (16), Plate 1, Fig. A.

FIG. 7. *Crenothrix polyspora*. Cells enclosed within a sheath of ferric hydrate, and showing false branching. Mag. about 390 ×. From Harder (16), Plate 3, Fig. B.

FIG. 8. *Crenothrix polyspora*. Conidia can be seen inside and coming out at the ends of the filaments. Mag. about 345 ×. From Cholodny (13), Fig. 5.
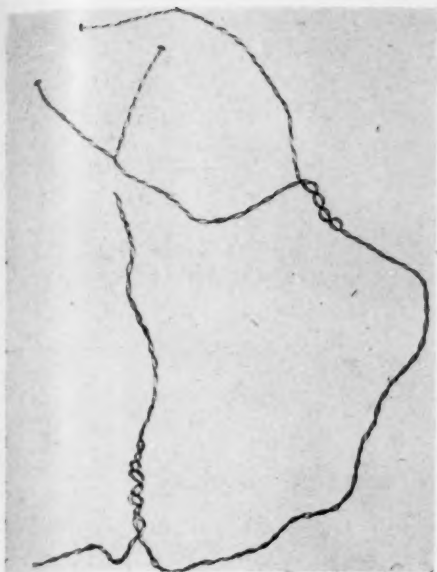
FIG. 9. *Gallionella ferruginea.* Sketch showing cells at the ends of the long, ribbon-like excretion bands. Mag. about 540 ×. From Cholodny (13), Fig. 9.
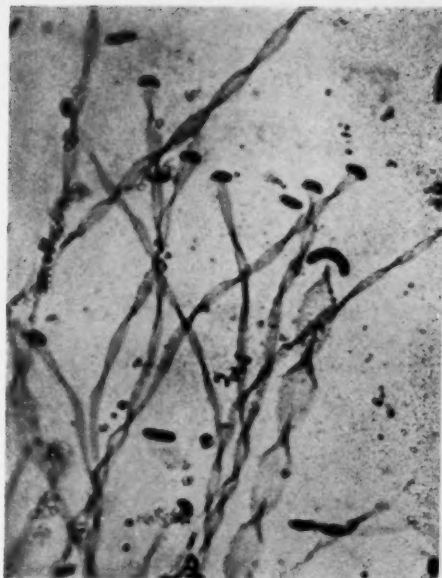
FIG. 10. *Gallionella major.* Curved cells at the ends of excretion bands. Mag. about 1120 ×. From Cholodny, *Planta,* V. 8, 1929, Fig. 6.
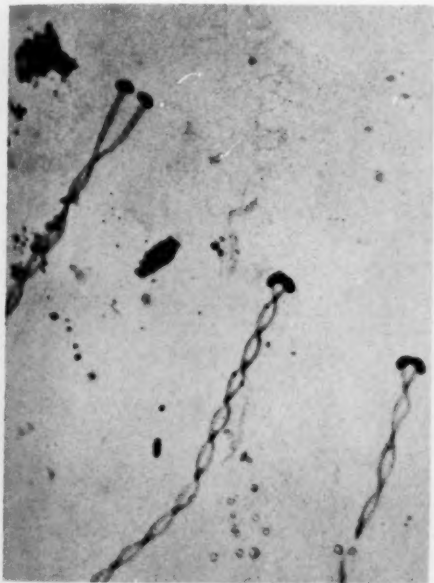
FIG. 11. *Gallionella major.* Cells at the ends of the excretion bands undergoing division. Mag. about 1180 ×. From Cholodny, *Planta,* V. 8, 1929, Fig. 3.
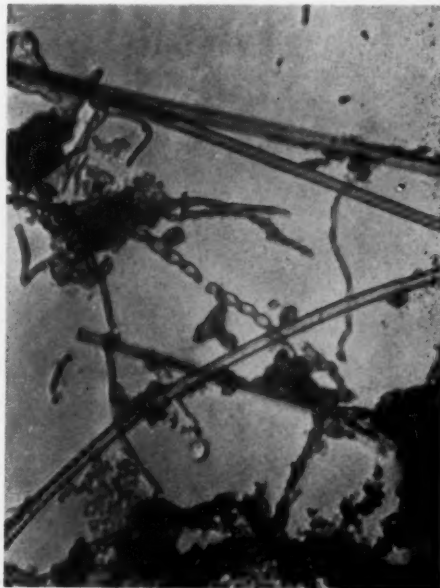
FIG. 12. Various iron bacteria including *Leptothrix* and *Gallionella* in accumulated precipitate of ferric hydrate in gallery water. From Tenny (8), Fig. 4.

Fig. 14. Curved small cells of *Sporovibrio desulfuricans*. Mag. about 1600 ×.

Fig. 13. Spiral cells of the sulfate-reducing bacterium *Sporovibrio desulfuricans*. Mag. about 1660 ×.

There has been an unwarranted tendency to label as *"Crenothrix* fouling" any trouble in water supplies caused by filamentous organisms without establishing the nature of the fouling organism.

Gallionella (*Spirophyllum*). The cells are asymmetrical and secrete ferric hydrate on one side to form a long slender twisted ribbon composed entirely of ferric hydrate. These ribbons serve as stalks which support the bacterial cells. The cells are small, curved, kidney-shaped rods $0.5 \times 1.2\mu$. Ferric hydrate is secreted from the concave side of the cells. They divide by transverse fission and, after division, each cell produces a secretion filament. At the point where cell division occurs, the secretion strand branches and this gives the erroneous impression that the organism itself is branched. The secretion filaments may attain a length of 200μ or more. The type species is *G. ferruginea*. Cells of *G. major* are larger ($1 \times 3\mu$). These bacteria occur in iron-bearing water, are sensitive to organic matter and are believed to be strict autotrophs.

Harder (16) states that *Gallionella* is one of the most widely distributed iron bacteria, nearly as commonly encountered as *Leptothrix*. *Crenothrix* and *Clonothrix,* he says, are somewhat less common.

Physiology

Although Ehrenberg associated micro-organisms with precipitation of iron in 1836 and Cohn presented a theory to explain this precipitation in 1875, particular interest in this phenomenon is traced to later work of Winogradsky whose ideas have dominated the subject as they have that of the physiology of the nitrifying and sulfur bacteria. His first report on

the iron bacteria, which appeared in 1888, followed studies of the sulfur bacteria which he had found were able to oxidize sulfur and utilize the energy released by this oxidation for their growth. It is not surprising that he came to the conclusion that iron bacteria were similar physiologically and that they used ferrous iron as a source of energy for development. It was Winogradsky who developed the concept of autotrophic bacteria, with which the iron bacteria and sulfur bacteria are classified. The autotrophic bacteria are characterized by the following physiological properties:

1. They can develop in a medium containing no organic material and they require no externally supplied organic substances.

2. Their carbon requirements can be satisfied by dissolved CO_2.

3. All of the required energy can be obtained from the oxidation of some specific incompletely oxidized inorganic substance.

In the case of strict autotrophic bacteria some organic materials are toxic except at extremely low concentrations and the bacteria are unable to utilize the organic compounds which are generally included in culture media. There are certain facultative autotrophic bacteria which can develop in media containing only inorganic substances but which are able to grow on organic compounds as well.

The reaction by which the iron bacteria are presumed to live as autotrophs is as follows:

$$4 \ \mathrm{Fe(HCO_3)_2} + 2 \ \mathrm{H_2O} + \mathrm{O_2} = 4 \ \mathrm{Fe(OH)_3} + 8 \ \mathrm{CO_2}$$
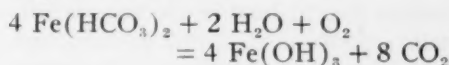
This is an exothermal reaction which is believed to release sufficient energy to satisfy all of the requirements of the

bacteria. The strictly autotrophic iron bacteria, such as *Gallionella ferruginea,* are believed to depend on this reaction, whereas the facultative iron bacteria, including *Crenothrix polyspora* and some species of *Leptothrix,* are not limited to growth at the expense of ferrous iron but can also grow on organic compounds. Thus, those bacteria which are able to grow on either ferrous iron or organic materials may produce large amounts of precipitated ferric hydrate when they live on the ferrous iron, and produce accumulations of filamentous fouling material under conditions where they develop on the organic constituents of the water. In the former case they live as autotrophic iron bacteria and in the latter case they grow as heterotrophic bacteria.

In his initial studies on iron bacteria, Winogradsky presented convincing evidence in support of his conclusions that they oxidize ferrous iron in their cells, precipitate the resulting ferric hydrate outside the cells, and utilize the energy liberated by the oxidation reaction. His explanation of the mechanism of precipitation of iron has received additional support from the results of numerous studies, particularly those of Lieske and Cholodny, but it has not been universally accepted, and many theories have been advanced to explain the nutritional peculiarities of the iron bacteria. The results of Molisch (18) and others, the latest being Cataldi (12), have shown that many of the iron bacteria are able to grow on organic materials, and there is reason to believe that at least in the case of certain organisms classified as iron bacteria, precipitation of iron is the result of the decomposition of organic compounds of iron and not the oxidation of inorganic iron compounds.

The reason why progress in the study of the physiology of the iron bacteria has been slow is that it is very difficult to cultivate these organisms in laboratory media. With a few exceptions, they cannot be grown on ordinary media, and there are no known simple procedures for cultivating them. As a result, in most cases, studies have been limited to microscopic observations.

A brief consideration of some of the factors affecting growth of iron bacteria may aid in suggesting the conditions under which they are likely to be encountered, as well as give some indication of their physiological characteristics.

Temperature. Some of the iron bacteria show preference for low temperatures. According to Lieske, *G. ferruginea* grew under laboratory conditions from 0° to 22°C. with an optimum of 6°C. It has been commonly encountered in springs and cool waters but also in water pipes. Volkova (19) found *Gallionella* in mineral springs with temperatures as high as 27° to 32°C. but not at 40° to 50°C. Species of *Leptothrix* have also been found in waters at 1° to 2°C. but their optimum is reported to be higher than that of *Gallionella.* Lieske and Molisch obtained good growth of *Leptothrix* at 25°C. Others reported the optimum temperature as 15°C.

Light. The iron bacteria are not sensitive to light and have been found in exposed locations and in shade as well as within pipes where light is completely excluded.

Concentration of iron. The iron bacteria are greatly affected by the presence of dissolved iron but they tolerate considerable differences in iron concentration. Though they have been found in waters with from 10 to 30

ppm. iron, they also occur where the amount of iron is as low as from 0.1 to 0.3 ppm., particularly in moving water where the supply of iron is continuously renewed. Harder (16) reports active development of iron bacteria in pipes carrying water with 1.3 ppm. iron. Halvorson (31) found them in springs having 1 to 10 ppm. Schorler (7) records incrustation of 10-cm. pipes carrying water with from 0.2 to 0.3 ppm. iron. In 30 years a deposit was formed 3 cm. thick, leaving an opening only 4 cm. in diameter. In contrast, Knudsen (4) states that to cause tuberculation the water must contain 2 ppm. or more. It has been stated that fouling by iron bacteria occurs only with water containing at least 0.2 ppm. iron. It may be concluded that, though iron bacteria are most likely to appear in water with relatively high iron content, they may develop in water with low iron concentration if the supply of iron is renewed in flowing water.

The general occurrence of iron bacteria in iron-bearing waters is one of the strongest arguments in favor of the idea that the iron plays some role of importance in the development of the bacteria and that the precipitation of iron is the result of some reactions intimately related to their physiology.

Reaction. The influence of reaction on iron bacteria is not definitely established, but there are indications that for many of the organisms slightly acid reactions, such as those caused by solution of considerable amounts of CO_2, are most favorable. Slight acidity increases the iron-carrying capacity of water. With regard to tuberculation, Reddick and Linderman (6) state: "Our investigations to date lead us to believe that an alkaline iron-bearing water, having only a small content of

organic matter, will not tuberculate, and that a slightly acid water containing iron and having a high organic matter content will readily tuberculate." Knudsen (4) also concluded that tuberculation was more likely to occur in slightly acid waters. On the other hand, Volkova (19) found *Gallionella* in mineral springs having a pH of from 7.0 to 7.6. Wilson (9) reports a case of profuse development of *Crenothrix* in a large main which carried water nearly free of iron and manganese and having a pH of from 7.3 to 8.0. The organism grew in gelatinous masses, and it was presumed that the iron was derived from the pipe through the bases of the bacteria. In this case there is reason to suspect that the water contained organic materials which supported growth of the bacteria. Hardman and Henrici (17) recovered *Siderocapsa* regularly from alkaline hard water lakes but never from neutral or acid soft water lakes. These authors, as well as Cholodny, express the opinion that iron precipitates only incidentally during the development of these bacteria and that organic matter supplies their energy requirements for growth. Cataldi (12) cultivated *Sphaerotilus* and *Leptothrix* at pH 6.8 but organic media were used and conditions were not representative of those under which iron becomes precipitated. Wilson (10) controlled fouling by *Crenothrix* by making the water alkaline (pH 8.5) with sodium carbonate. Control may have been effected by making the reaction unfavorable to the iron bacteria, or it may have been due to the elimination of iron, manganese or organic matter upon which the bacteria depended for growth.

Oxygen. The iron bacteria are aerobic and as such are dependent on the presence of free oxygen. In stag-

nant water they are found only at the surface but they may find conditions favorable for growth below the surface adjacent to green plants which liberate oxygen through photosynthesis.

Organic matter. There is much conflicting evidence regarding the influence of organic materials on iron bacteria, but it has been definitely established that some of these organisms can grow on organic compounds, and it appears probable that at least some of the organisms which are now classified with iron bacteria actually require organic matter for growth. *Sphaerotilus* (*Cladothrix*) has been repeatedly grown on organic media, first in 1904 by Adler who used iron ammonium citrate, and subsequently by Molisch on mangan peptone, iron ammonium tartrate and other organic compounds. Most recently, Cataldi (12) reported that *Sphaerotilus,* as well as *Leptothrix,* was readily cultivated on organic media, but that it failed to grow in mineral media in which ferrous and manganous salts were used as the only sources of energy. Molisch carried *L. crassa* through 47 successive transfers in a nutrient solution containing from 1 to 2 per cent peptone to which no iron was added. Under these conditions the cells were colorless and had no iron in their delicate sheaths.

Although these results indicate that some of these bacteria can grow in the absence of organic matter, they do not prove that the bacteria are unable to grow by the oxidation of ferrous iron under suitable cultural conditions. In fact, it is significant that no one has succeeded in obtaining growth of *Gallionella* in organic media. Furthermore, Lieske found that certain organic compounds were actually toxic. Concentrations of from 0.25 to 0.35 per

cent of asparagin, sucrose and peptone inhibited growth; some depression was noted even at 0.01 per cent. This response is similar to that of some other autotrophic bacteria and suggests that *Gallionella* may indeed be strictly autotrophic. *Gallionella* has been encountered, nevertheless, in waters containing considerable organic matter, such as water in aquariums and ditches, as well as in springs and streams which are relatively free of organic matter.

On the basis of the scattered evidence of the influence of organic matter on the iron bacteria it may be tentatively concluded that *Sphaerotilus, Siderocapsa* and *L. crassa* require organic matter and may be strictly heterotrophic, that *Crenothrix* and *Leptothrix ochracea* are facultative autotrophs and that *Gallionella* is strictly autotrophic. In waters containing relatively large amounts of organic matter it is common to encounter *Crenothrix* and *Leptothrix,* whereas in water low in organic matter *Gallionella* is prominent.

Sources of nitrogen. The amounts of nitrogen required by the iron bacteria are very small compared to the requirements for iron and it is probable that the nitrogen content of most waters meets their needs. There is no specific information regarding the nitrogen compounds that they use, but some information can be obtained by checking the constituents of the culture media which have been used to grow the bacteria. Some of the media contained complex and diverse organic compounds of nitrogen, such as beef extract, peptone and plant extracts. Iron bacteria have also been cultivated in simpler media containing iron ammonium citrate and similar compounds and presumably the bacteria used the ammonium nitrogen to meet their re-

quirements. Lieske stated that he succeeded in growing a culture of *Leptothrix* in a strictly mineral medium in which the nitrogen was supplied as ammonium sulfate. The medium in which he grew *Gallionella* contained both ammonium and nitrate nitrogen and it cannot be stated which was used by the organism. No definite conclusion can be drawn from such incomplete information except that certain bacteria can use inorganic nitrogen. It is of interest to note, however, that with some of the autotrophic bacteria, ammonium nitrogen is preferred or required and that nitrate nitrogen and certain amino acids are even toxic. With some other bacteria as well, such as the methane bacteria, ammonium nitrogen is used, whereas nitrate is toxic.

Transformations of Iron by Non-specific Bacteria

In most discussions of iron precipitation by micro-organisms, principal attention has been devoted to the iron bacteria, in fact almost to the exclusion of all other microbial activities which may be directly or indirectly related to the phenomenon. This is an oversimplification of the subject and inadequately evaluates other important bacterial activities. As with all transformations in nature, iron precipitation in water occurs in the presence of numerous micro-organisms and under conditions where various strictly chemical reactions may alter the solubility of iron.

In cases where the transformations of iron are due to non-specific bacteria, the iron has no particular significance in the metabolism of the bacteria but is altered as a result of changes in the medium brought about by bacterial development. From the following re-

actions it is possible to make some predictions regarding the changes which may occur as a result of changes in reaction (pH) as well as those controlled by oxidation and reduction (33):

In the presence of solid ferric hydrate

$$\frac{[Fe^{++}]}{[H^+]^2} = \frac{K}{[O_2]^{0.25}}$$

Under atmospheric conditions or with constant oxygen pressure the reaction becomes

$$\frac{[Fe^{++}]}{[H^+]^2} = K'$$

In cases where the solution is saturated with iron, where there is an excess of solid ferric hydrate and where the oxidations by molecular oxygen are reversible, changes in the hydrogen-ion concentration and the oxygen pressure (degree of oxidation or reduction) will result in changes in the amounts of iron in solution. With a decrease in the oxidizing intensity, but at constant pH, there will be an increase in the concentration of ferrous ions. Since ferrous iron is more soluble than ferric iron, some of the solid ferric hydrate will go into solution and become reduced. With increasing oxygen pressure at constant hydrogen-ion concentration there will be a tendency for ferrous iron to become oxidized to ferric and, if the solution was initially in equilibrium, the increase in ferric iron will result in precipitation and a decrease in the amount of iron in solution.

With increase in hydrogen-ion concentration, but at constant oxygen pressure, there will also be an increase in the amount of dissolved ferrous iron through reduction of some of the ferric iron, which will cause some of the solid ferric hydrate to go into solution.

TABLE 1

Influence of Bacterial Development on Solution and Precipitation of Iron

Medium	pH		Fe++ in Solution, *mg./100 ml.*	
	Anaerobic	Aerobic	Anaerobic	Aerobic
Dextrose	3.0	3.1 3.1*	0	0 0*
Dextrose + Fe(OH)₃	6.0	5.3 4.2*	71.88	12.50 11.88*
Dextrose + Fe(OH)₃	6.0	4.6 4.3*	73.75	21.88 12.50*
Peptone	6.2	8.0 7.8*	0	0 0*
Pe ptoe + Fe(OH)₃	6.4	8.2 8.0*	22.98	0 0*
Peptone + Fe(OH)₃	6.4	7.7 7.7*	16.25	0 0*

* Cultures treated with phenol at time of exposure to free air.

With decrease in the hydrogen-ion concentration, there will be a tendency for ferrous iron to be oxidized to ferric iron and precipitate. Some of the data in Table 1 show that during bacterial development in organic media, where conditions became strongly reducing because of lack of diffusion of oxygen, iron went into solution. In this experiment, culture media treated with either dextrose or peptone, with or without ferric hydrate, were inoculated with soil and incubated for three weeks. The medium nearly filled the culture flasks and thus suppressed diffusion of oxygen. As shown in the next to the last column, considerable iron was dissolved in the dextrose medium. This was due in part to the production of acid and it can be noted that the iron exerted a buffering effect and prevented the shift to the low pH shown in the medium containing no iron. The reaction of the peptone medium re-

mained nearly constant irrespective of the presence of ferric hydrate and, even though the pH was close to neutrality, appreciable iron remained in solution. The results show that iron was dissolved under anaerobic conditions not only during decomposition of the carbohydrate where there was an increase in the acidity, but also during decomposition of nitrogenous materials where there was relatively little change in pH.

After the cultures had developed for three weeks, the solutions were poured into flat vessels to provide large surfaces in contact with the air. During the two-week period that these cultures were kept under aerobic conditions all of the iron precipitated from the peptone solutions and a large part disappeared from the dextrose media, but some iron still remained in solution. These changes were independent of the action of bacteria, since phenol-treated solutions behaved the same as

those in which no attempt was made to control bacterial development. Precipitation was doubtless due to an increase in the oxidizing intensity. It is of interest that there was an increase in the hydrogen-ion concentration in both the sterile and non-sterile dextrose solutions during aerobic treatment.

Even though the solutions which initially contained dextrose became more acid during exposure to the air, less iron was held in solution. This may seem contradictory, since an increase in the hydrogen-ion concentration favors solution of iron. The changes in amounts of dissolved iron were caused by an increase in the oxidizing intensity and not the hydrogen-ion concentration. In fact, the completeness of precipitation of the iron during exposure to the air was probably limited somewhat by the acidity; if the reaction had remained close to neutrality, it is probable that all of the iron would have been precipitated.

Changes such as these are not due to the action of any specific bacteria nor are they caused by bacteria alone, but they can be effected by various micro-organisms and the extent of the changes is proportional to the alteration in the reaction and in the degree of oxidation. The principal effect of the bacteria in the experiment mentioned above was the solution of iron; the precipitation was the result of strictly chemical reactions. It can be concluded that generally an increase in the oxygen pressure or a decrease in the hydrogen-ion concentration leads to oxidation of iron and its precipitation.

Precipitation of iron by algae and other water plants may be cited as another example of a reaction which has no direct connection with the growth of the organism responsible for the change. These green plants liberate oxygen by photosynthesis and thus provide more strongly oxidizing conditions in the water, leading to the oxidation and precipitation of iron on the plant surfaces. This type of reaction is relatively common in iron-bearing waters.

Mention should be made also of some of the changes which are caused by differences in the concentration of dissolved carbon dioxide (31). This gas is produced in such abundance that in some subterranean waters it greatly affects the solubility of iron. It is also produced in quantities by micro-organisms, by animals and by higher plants in the dark. Relatively large amounts of CO_2 may be removed from solution by green plants during photosynthesis. The mixed population of micro-organisms in general tends to increase the carbon dioxide concentration.

In order to follow the influences of carbon dioxide on iron concentrations, consider a solution which is saturated with CO_2 and in which there is an excess of solid ferrous carbonate. If CO_2 is removed from such a solution some of the solid ferrous carbonate goes into solution to replace the dissolved CO_2. This increases the ferrous iron concentration above the stable value and results in its oxidation to ferric iron followed by its precipitation as ferric hydrate. As more CO_2 is removed this sequence of events continues until all of the solid ferrous carbonate has become dissolved. The amount of iron remaining in solution at the time when the CO_2 has all been removed would be determined principally by the reaction (pH) of the solution. The more acid the solution the greater would be the amount of dissolved iron. One would expect that there would be a slight decrease in the

hydrogen-ion concentration as the CO_2 was removed after the last portion of solid ferrous carbonate had gone into solution.

If CO_2 were added to a solution which was saturated with ferric hydrate and in which there was an excess of ferric hydrate, there would be at first a slight increase in acidity. Some ferric hydrate would go into solution and a portion of this would be reduced to ferrous carbonate. Thus, in water stored under conditions where there is an increase in the CO_2 concentration, conditions are favorable for solution of iron. As more ferrous carbonate was produced with the addition of more CO_2, the solution would become saturated, and further addition of CO_2 would result in the precipitation of ferrous carbonate. Continuous addition of CO_2 would cause solution of more ferric hydrate and result in its reduction and subsequent precipitation as ferrous carbonate. This would continue until all of the ferric hydrate had become dissolved.

Thus by decreasing the partial pressure of CO_2 in the atmosphere below that of the solution there will be a tendency for CO_2 to come from the solution and this will favor precipitation of ferric hydrate. In addition, when the oxidation-reduction potential is increased there will be a tendency for oxidation and precipitation of iron. Consequently, when subterranean waters come to the surface, conditions are favorable for both of these changes. In many cases this is responsible for the precipitation of ferric hydrate from the iron-laden waters issuing from the earth. The CO_2 escapes and there is some decrease in acidity, and this is followed by oxidation of ferrous to ferric iron which is precipitated as ferric hydrate. These changes can occur in the absence of micro-organisms but it is possible that various organisms accelerate the reactions.

In studying the iron bacteria and other micro-organisms concerned in iron precipitation, organic media have been frequently used and, as mentioned earlier, ferric ammonium citrate is one of the common medium constituents. Although large amounts of organic compounds of iron may remain in solution at alkaline reactions, they remain soluble by reason of the fact that they are poorly ionized. If such compounds are decomposed by micro-organisms, ionic iron is released in the medium and precipitates as ferric hydrate. There is nothing specific about the organisms concerned in this transformation except their ability to decompose the organic portion of the compound. Studies with ferric ammonium citrate are particularly informative in this connection. *Escherichia coli* and *Aerobacter aerogenes* differ in ability to decompose citrate. If flasks of a culture medium containing ferric ammonium citrate are inoculated with these two bacteria, iron will precipitate from the solution inoculated with *Aer. aerogenes*, but not from the one inoculated with *Esch. coli*. Iron precipitation by phenomena of this type is widespread. Many different organic compounds of iron occur in natural waters and various bacteria are concerned in the precipitation of iron from them.

In certain cases, the opposite may occur. During decomposition of organic matter by micro-organisms, iron may combine with some of the products of decomposition and form stable organic compounds. Thus, in certain locations iron may go into solution through microbial action and be pre-

cipitated some distance away through breakdown of the initially produced organic compounds.

Consideration of the various ways in which micro-organisms can affect the solution and precipitation of iron leads to the conclusion that iron bacteria are not the only agents of iron transformation but that various other bacteria may be of considerable importance.

Sulfur Bacteria

Some of the sulfur bacteria are occasionally encountered in water, particularly in water containing sulfide or elemental sulfur. In exceptional cases filamentous sulfur bacteria have been troublesome as fouling organisms. Other sulfur bacteria may cause corrosion.

The sulfur bacteria as a group are characterized by their ability to oxidize sulfur or various sulfur compounds, generally to sulfate, and to utilize these reactions in their development. There are morphologically different sulfur bacteria, varying from the complex filamentous organisms, some of which are pigmented and photosynthetic (20, 24), to the small simple bacteria which are hardly distinguishable morphologically from *Esch. coli* (23). The filamentous forms are typical water organisms and are sometimes encountered together with iron bacteria in water basins and even in water distribution systems. Little need be said regarding these organisms except that they may contribute to the formation of slimes and possibly to the tastes which develop in water where there is growth and breakdown of the slime films.

One of the typical, simple sulfur bacteria may bring large amounts of iron into solution under conditions favorable for its development. This is

Thiobacillus thiooxidans, an aerobic bacterium which has the capacity of oxidizing sulfur and certain incompletely oxidized sulfur compounds with the production of very high acidity (22). It is able not only to tolerate high acidity but to produce the acid as well. It has been recovered principally from soils and sulfur springs but it may also be encountered in water under special conditions. In several instances it was isolated from soils where the acidity was so extreme as to indicate an abnormality. In artificial media it has been cultivated at reactions close to pH 0 and it has produced acidity as high as 10 per cent sulfuric acid.

One of the most remarkable phenomena in which this organism played an important part was that recently reported by Harmsen (21), dealing with changes in some soils of the Wieringen Polder, an area of land reclaimed from the Zuiderzee in Holland. The bottom material of this arm of the ocean was black with sulfide. When the area was diked, the water pumped out and the soil drained, the sulfide underwent change, partly chemical and partly bacteriological. Some of the sulfide was oxidized to elemental sulfur, which was then attacked by *T. thiooxidans.* In locations where there was an abundance of lime in the soil the sulfuric acid which was formed became neutralized, as a result of which the rate of reclamation was greatly accelerated. In locations where there was little or no lime there was a rapid increase in acidity and large amounts of iron were dissolved from the soil materials. This went on to such an extent that quantities of basic ferric sulfate accumulated in the soils and gave them a characteristic yellowish to gray color. In some of the poorly buffered sandy soils the reaction became exceedingly

acid and in certain cases even had a negative pH.

It has been reported that these bacteria are concerned in the corrosion of iron pipelines. One case has been reported where a calking compound which contained sulfur was responsible for the trouble. When the sulfur was attacked by *T. thiooxidans* sufficient acid was produced to corrode the pipe severely at the joint.

Abnormally high acidity (below pH 2.0) has in the past served as a clue leading to the detection of this bacterium and to its identification as the agent responsible for the acid condition.

Sulfate-Reducing Bacteria

The sulfate-reducing bacteria are responsible for still other iron transformations than those discussed thus far. Sulfide, which is one of the principal products of their development, reacts with dissolved iron or metallic iron to form black insoluble iron sulfide. Furthermore, the bacteria have assumed particular significance since it was discovered that they are agents of corrosion.

They are not the only bacteria which form sulfide but they produce most of the sulfide of bacterial origin. Some sulfide is produced by various bacteria during decomposition of organic sulfur compounds under conditions of deficient aeration such as occur in sewage. Sulfide can also be formed by numerous bacteria by reduction of sulfite, thiosulfate, elemental sulfur and other incompletely oxidized inorganic sulfur compounds. Most of the sulfide in black muds of ocean sediments and tidal basins, as well as in poorly drained heavy soils, comes from the reduction of sulfate.

The bacteria which reduce sulfate to sulfide are of considerable interest, par-

ticularly because of their ability to effect this reaction. So far as is known there is only one specific group of bacteria which can reduce sulfate to sulfide. Thus, the sulfate-reducing bacteria are a highly specialized physiological group. Furthermore, they are morphologically distinct. They are curved cells, occasionally having a spiral shape. They are actively motile and form spores under suitable conditions. From time to time they have been listed under the genera *Spirillum, Microspira, Vibrio, Desulfovibrio* and, most recently, *Sporovibrio*. The most common species are *Sporovibrio desulfuricans* and *S. rubentschickii*. They are strict anaerobes and are heterotrophic. Sulfate is the specific hydrogen acceptor which serves the same purpose as free oxygen in the development of strict aerobic bacteria. Organic materials which provide energy for the growth of the sulfate-reducing bacteria become oxidized by the sulfate which is reduced to sulfide. One of the typical reactions whereby lactate is broken down to acetate and CO_2, and whereby sulfate is reduced to sulfide, is shown below:

$$2\ CH_3.CHOH.COONa + CaSO_4$$

Sodium lactate

$$=\ 2\ CH_3.COONa + H_2S$$

Sodium acetate

$$+\ CaCO_3 + CO_2 + H_2O$$
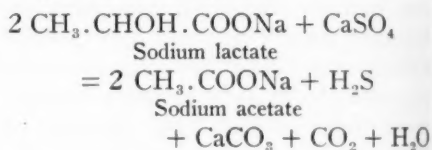
This reaction is exothermal and can provide all the energy necessary for development of the bacteria. Many different compounds can be used, including numerous organic acids, carbohydrates, alcohols, amino acids and more complex organic nitrogenous substances.

The different species of sulfate-reducing bacteria are alike morphologically as far as is known and they differ

only in the organic compounds which they are able to attack (28).

These bacteria are of some importance in water distribution systems in that they produce sulfide which is dissolved in the water and makes the water objectionable by reason of the odor, the presence of suspended black particles and the corrosive effect of the sulfide on steel and other metals. They are of still greater importance as corrosive agents through another mechanism of action.

Their relationship to this corrosion process was discovered in 1934 by von Wolzogen Kühr (30) who showed that these bacteria cause corrosion under anaerobic conditions where it would be expected that the iron would remain passive. He was led to conclude that the bacteria were responsible for corrosion, since iron sulfide was one of the principal products of corrosion; that sulfate was reduced during the process; that hydrogen was taken up by micro-organisms where corrosion occurred; and that the sulfate-reducing bacteria were active in the anaerobic soils and environments where corrosion occurred. There is nothing unusual in the bacterial corrosion process that distinguishes it from the generally accepted electrochemical mechanism of corrosion except that the bacteria serve to activate the cathodic hydrogen. Under aerobic conditions this hydrogen is oxidized by oxygen of air in the process of rusting, as shown below.

Under conditions where oxygen is excluded, the system becomes polarized, since the hydrogen which accumulates at the cathode is not removed. In the absence of some depolarizing agent there is no corrosion. The sulfate-reducing bacteria serve as depolarizing agents under anaerobic conditions by removing the hydrogen and oxidizing it at the expense of sulfate which is reduced to sulfide. The reactions on page 980 were proposed to explain this transformation.

As will be seen from the last equation, the products of corrosion are ferrous sulfide and ferrous hydrate, the quantities of which are in the proportion of 1 to 3. Following von Wolzogen Kühr's study of the process, others have sought to establish whether or not anaerobic corrosion was a factor of importance in various locations throughout the world (25, 26, 29). Principal interest has been focused on corrosion in soil. Results of numerous studies have indicated that this type of corrosion is not only widespread but may be so severe as to cause pipe failure within a period of a few years. A steel pipe 200 mils thick may be penetrated in eight to ten years under conditions where this corrosion is severe (26).

With steel the metal is pitted and frequently the pits are sufficiently close together to coalesce and cause slab corrosion. Under this condition a large portion of the pipe surface may lose

$$4HOH \rightleftharpoons 4H^{\cdot} + 4OH' \left.\right\}$$
$$2Fe + 4H^{\cdot} \rightleftharpoons 2Fe^{\cdot\cdot} + 4H \left.\right\} \text{Anodic solution of iron}$$

$$4H + O_2 \rightarrow 2HOH \qquad \text{Depolarization}$$

$$2Fe^{\cdot\cdot} + 4OH' \rightarrow 2Fe(OH)_2 \left.\right\}$$
$$2Fe(OH)_2 + \tfrac{1}{2}O_2 + H_2O \rightarrow 2Fe(OH)_3 \left.\right\} \text{Corrosion products}$$

$$3HOH + 2Fe + 1\tfrac{1}{2}O_2 \rightarrow 2Fe(OH)_3 \qquad \text{Summary}$$
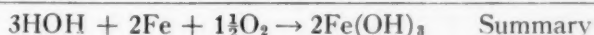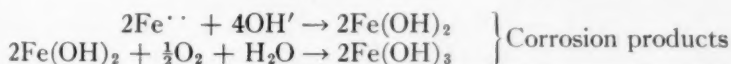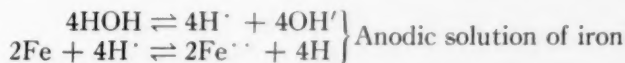
metal, but at different rates so that the metal surface is very uneven. When a corroding steel surface is exposed, the spots where corrosion had occurred appear as raised areas where the corrosion products had accumulated.
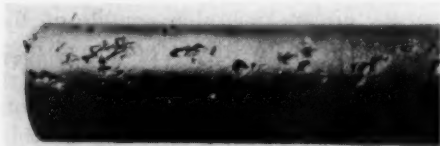
FIG. 15. 6-in. Steel Pipe Pitted by Anaerobic Corrosion During Eight Years Burial in Soil—Specimen Provided by R. F. Hadley.

There is frequently a hard black crust of corrosion products, beneath which is softer material which is black or mixed black FeS and white ferrous hydrate. When the corrosion products are removed the metal surface is bright and silvery. There is no tendency for the corrosion products to adhere tightly to the metal surface and thus to stifle corrosion, as sometimes occurs with rusting.

With cast iron a condition is encountered which has been called "graphitization." Iron showing such attack is somewhat soft and can be penetrated with a knife. This is caused as a result of loss of iron from the pipe, leaving a porous residual structure consisting of a mixture of iron and carbon which resembles graphite. When the pipe dries out this material hardens.

Graphitization does not always characterize anaerobic corrosion of cast iron. In some cases there is a heavy accumulation of corrosion products which may be an inch or more in thickness and contain an abundance of ferrous sulfide. Beneath this crust the metal is bright but not noticeably softened. In such cases it seems likely that most of the iron has come from the surface of the pipe.

This type of corrosion is not confined to soils, although most of the studies have been made on metal buried in soils. It also occurs in fresh water and salt water, as well as in the sediments and bottom materials of lakes, rivers and oceans. It has been encountered in various tanks where sediment covered the steel surface or where the metal was incompletely coated so as to exclude oxygen or oxygenated water without preventing exchange of salts and organic materials contained in the water. Anaerobic corrosion is important in sewerage equipment where anaerobic conditions prevail.

Conditions are more readily controlled in domestic water distribution systems than in sewage where there is intense bacterial activity supported by the abundance of organic matter. Pomeroy (27) reported an interesting case where an 8-in. cast-iron pipe became nearly filled with corrosion products consisting principally of iron sulfide and iron oxide. After 13 years only a 3-in. opening remained. The

$$8HOH \rightleftharpoons 8H^{\cdot} + 8OH' \atop 4Fe + 8H^{\cdot} \rightleftharpoons 4Fe^{\cdot\cdot} + 8H \}$$ Anodic solution of iron

$$CaSO_4 + 8H \rightarrow H_2S + 2HOH + Ca(OH)_2$$ Depolarization

$${Fe^{\cdot\cdot} + H_2S \rightarrow FeS + 2H^{\cdot} \atop 3Fe^{\cdot\cdot} + 6OH' \rightarrow 3Fe(OH)_2} \}$$ Corrosion products

$$4Fe + CaSO_4 + 4HOH \rightarrow FeS + 3Fe(OH)_2 + Ca(OH)_2$$ Summary
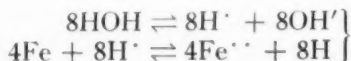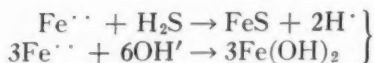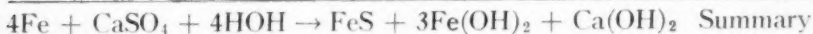
conditions under which the corrosion occurred and the nature of the corrosion products suggest that there had been anaerobic corrosion.

There is still another type of corrosion associated with development of both sulfate-reducing bacteria and sulfur bacteria which has been encountered in both iron pipes and concrete conduits. In cases where the water contains sulfide or where sulfide is produced as in sewage, and the pipe is only partly filled so that there is an air blanket over the water, some of the sulfide becomes dissolved in the moisture film on the upper walls of the pipe. Here it undergoes oxidation, caused principally by sulfur bacteria, and the sulfuric acid which is formed attacks the pipe, causing its disintegration.

It has been definitely established that under certain soil conditions the exterior of pipes may be attacked by anaerobic corrosion, but little consideration has as yet been given to the possibility that this corrosion is a factor on the inside surface of water pipes. Water is generally well supplied with oxygen and it might seem unlikely that conditions would be favorable for development of anaerobic bacteria. Nevertheless, there are certain conditions under which this type of corrosion may occur, one of which is a metal surface coated with ferric hydrate and other fouling material such as that produced by iron bacteria. Although the organisms which produce the incrustation and accumulate the fouling material are not themselves corrosive, there is some evidence that corrosion occurs beneath the nodular accumulations. This corrosion may be the result of electrolysis caused by differential aeration, but it seems more likely that in some cases at least there has been anaerobic corrosion. The

mixture of ferric hydrate and organic materials could serve as a barrier preventing oxygenated water from reaching the metal surface and thus provide anaerobic conditions. The accumulations should not be so tight as to exclude contact of the films of water with the metal. Furthermore, there should be an exchange of dissolved materials between the main body of water and the water in contact with the metal. This set of conditions should favor development of anaerobic sulfate-reducing bacteria; they could obtain a supply of nutrient elements from the water films, possibly some organic matter from the same source, and some organic nutrients from residues of microbial cells contained in the layer of material coating the metal.

The possibility of anaerobic corrosion under these conditions is not entirely theoretical. The appearance of the underlying metal in badly fouled pipes suggests that anaerobic bacteria develop at the metal surface. Larson (5) reported that at pipe joints and extending from these points for various distances there was an accumulation of material consisting of a surface crust of hard, yellow-brown material beneath which was black loose slime containing sulfide. He stated, "The outer coating does not appear to be sufficiently impermeable to prevent corrosion, but appreciable inhibition is afforded." The descriptions by Reddick and Linderman (6) and Knudsen (4) of the tubercles on water mains leave little doubt regarding the presence of sulfate-reducing bacteria in the tubercles. Furthermore, these incrustations were also found to produce conditions favorable for corrosion. The cone-like structures were described as consisting of an outer coating of red ferric oxide mixed with black magnetic

iron oxide and of a center which was black and soft and frequently contained sulfide. When the black material was exposed to the air it became oxidized to red ferric oxide. Beneath the tubercles which tended to coalesce and cover large areas there were pitting and other evidences of corrosion.

Methods of Study

The relationships of micro-organisms to iron transformations are such that no single set of methods can be used to determine the nature of the organisms or their role in the transformations. The organisms are diverse, and special procedures are required for each group. No routine chemical or cultural tests have been developed such as those which are so effectively used to test water for sewage pollution. In order to determine whether such bacteria as those under discussion are responsible for undesirable conditions in the water or the distribution system it is of primary importance to know the characteristics of these bacteria.

Study of the iron bacteria is complicated by the fact that there are no simple methods for their cultivation. Whereas some of these bacteria have been grown in pure culture in artificial media, this is not readily accomplished. In only a few instances have iron bacteria been grown at all in inorganic media. Their study is consequently limited almost entirely to microscopic observations and simple chemical tests.

Material suitable for examination may be obtained from fouled surfaces, but only fresh material should be used, since the cells become distorted by desiccation and the material in which they are imbedded cannot be readily redispersed. With water which supports active development of iron bac-

teria, culture material may be obtained by running a slow stream into a glass cylinder or over a trough for several days. A slimy growth may appear in which there are iron bacteria together with precipitated ferric hydrate. This material can then be used for microscopic studies. Culture slides or cover slips can be kept submerged in the running water for days or weeks and the iron bacteria which become attached to the surfaces can be studied. Wilson (9) suggested that glass slides be inserted in pipes in specially devised stuffing boxes in such a manner that the bacteria would be able to develop under conditions which are typical for the inside of the pipes. Periodically the slides could be removed and studied to determine the abundance and type of organisms which become attached to the slides. Metal slides could also be similarly used in cases where it was desirable to make tests under conditions more representative of the pipes themselves.

Microscopic preparations should be first examined in a fresh condition and before treatment with any chemical. The material could be subsequently treated in various ways to bring out the characteristics of the bacterial cells. *Gallionella* can be stained with crystal-violet or carbol-fuchsin in a wet preparation in order to reveal the terminal curved cells at the ends of the bands of ferric hydrate excreted by the bacteria. Many of the iron bacteria are so coated with deposits of ferric hydrate that the characteristics of the cells cannot be distinguished until the preparations are treated with dilute acid which removes most of the ferric hydrate. Acid treatment is not desirable in the case of *Gallionella* since this dissolves the characteristic bands of excreted material. Preparations of

other iron bacteria which have been treated with acid and subsequently washed in water can be stained with the common bacteriological stains or with dilute iodine solution which stains the cells very lightly and reveals cell structures which are obscured when other stains are used.

The presence of iron in the accumulated material where the bacteria develop is generally so obvious that it is not necessary to test for it but it may be desirable to test for the relative abundance of iron and manganese in the products.

Where attempts are made to grow the organisms it should be kept in mind that the iron bacteria are aerobic, and that many of them grow best at neutral or slightly acid reactions, and that the temperature of incubation should be fairly low. Some of the bacteria grow best at 10°C. or less. The methods which have been most successfully used to cultivate the iron bacteria have been summarized by Cholodny (14).

Study of the sulfur bacteria also requires the use of special methods. Some of the higher filamentous sulfur bacteria can be recognized by the occurrence of highly refractive globules of sulfur within the cells (20, 24). They may appear in sulfide-containing water which is brought in contact with the air. During growth of these bacteria there is a decrease in the sulfide, an increase in the acidity and an increase in the amount of sulfate, all of which can be tested. Though the filamentous sulfur bacteria are not readily cultivated in artificial media, some of the simple sulfur bacteria will grow in special solution media (22, 23) and their relative abundance can be determined.

The anaerobic sulfate-reducing bacteria are also a distinct physiological group of organisms. Their development is characterized by the accumulation of sulfide which reacts with iron to produce black iron sulfide. Water in which they develop may become black or have a sulfide odor. In special cases the activity of these organisms is confined to certain areas of the pipe surface. At these locations there is black material which should give a positive test for sulfide. Sulfate-reducing bacteria can also be cultivated in special media (28), by use of which their relative abundance can be determined and their morphological characteristics ascertained.

References

Iron Bacteria As Fouling Organisms

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Trends in Water Laboratory Practice

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THE current trend in water laboratory practice is from chemical to physical methods of analysis. The time-honored routine of "precipitating, filtering, igniting and weighing" is rapidly losing ground and the progressive technician must become familiar with an increasing array of technics and instruments that belong primarily to the fields of physics and engineering.

In order to study this trend, a questionnaire covering laboratory equipment and analytical methods was sent to 46 representative water laboratories. The answers to this questionnaire proved to be of considerable value in the re-evaluation of current laboratory procedures and it was thought that a summary of this information might suggest to other laboratory workers new methods and equipment to use in their studies and investigations.

Replies were received from 41 laboratories, classified as follows:

Laboratory Classification	Number Reporting
Commercial and consulting	11
Federal and state public health	13
Federal and state water resources	3
Municipal water works	11
Railroad	1
University (sanitary engineering)	2

Geographical distribution was as follows: Canada 1, East 9, Middle West 13, Pacific Coast 9, South 3 and Southeast 6.

Table 1 is a record of the equipment used by the participating laboratories.

The list was confined to equipment used for the mineral analyses of water and to supplemental rather than basic items.

Equipment Questionnaire

Current advances in instruments and instrumentation are producing a body of knowledge which comprises an entire subject by itself and will be touched upon here only briefly. For a very excellent and comprehensive discussion of present-day instrumentation the reader is referred to the works of Müller (1, 2).

Widespread publicity has been given to pH as the key to the solution of all water problems. This is reflected in the fact that 37 of the 41 reporting laboratories have potentiometric instruments for pH determination. In addition, fifteen laboratories use potentiometric titration technics. More than half estimate total solids by conductivity. The present trend in current measurement appears to be toward visual indicators, such as the alternating current galvanometer and the electronic bridge-balance indicator. The conventional telephone receiver has been found to be neither convenient nor comfortable and is disadvantageous especially in portable equipment.

Due to their speed and sensitivity colorimetric methods of analyses have always been popular with laboratory personnel. With new and improved

TABLE 1

Summary of Equipment Used by 41 Water Laboratories

pH meter	37	Microscope	39
Electrometric titration apparatus	15	Clinical (oil immersion) 33	
		Petrographic accessories 5	
Conductivity equipment	22	Stereoscopic low-power 10	
Microphone hummer and telephone receiver 9			
Alternating current galvanometer 8		Centrifuge	30
Electronic bridge—balance indicator 7		Vacuum pump	29
		Radioactivity apparatus	4
Electrodeposition equipment	5	Photomicrographic equipment	11
Polarigraph	2	Metallographic equipment	2
		Microchemical apparatus	4
Colorimetric equipment	30	Glassblowing equipment	19
Colorimeter 24		Spectrometer	3
Photo-electric photometer 17			
Abridged spectrophotometer 5		Spectrograph	4
Spectrophotometer 5		Quartz 2	
		Grating 2	
Turbidimeter	34		
Jackson 31		Laboratory water still	34
Hellige 12		Demineralized water by cation-anion exchanger	1
Baylis 7			
St. Louis type 1		Vacuum oven	1
Parr 1		Gas analysis equipment	3
Special design—photo-electric 3		Potentiometric temperature recorder	1
Special design—optical 2			

instruments becoming commercially available, even greater emphasis is being put on this technic. This statement is strikingly confirmed by the fact that approximately 70 per cent of all recent articles on water analyses recommend the use of such instruments. All but ten of the reporting laboratories employ instruments using this principle. A trend from visual to photo-electric methods of colorimetric analysis is also evident. Seventeen laboratories have photo-electric colorimeters and in addition ten have spectrophotometers or abridged spectrophotometers. The relatively inexpensive photo-electric colorimeter is superior to visual methods because it eliminates errors due to personal factors and gives better reproducibility of readings than is possible with the eye. Unfortunately, however, most of them employ barrier-layer cells which are

notoriously insensitive at low levels of illumination. The most reliable general utility instrument appears to be the spectrophotometer because any colorimetric problem can be reduced to the fundamental wave-lengths involved.

Although the listing of four spectrographs cannot be called a stampede to the spectrographic method of analysis, this is a good showing when the relatively high initial expense is considered. Spectroscopy is one of the most reliable means of identifying elements known. This is due to the fact that each element, under suitable conditions of excitation, will emit characteristic spectral lines. The instrument which produces these lines and records them on a photographic emulsion is called a spectrograph. The image may be recorded on plates or film and the intensity of the characteristic lines measured photo-electrically. The plotting

of intensity against concentration gives quantitative measurements and furnishes a most useful analytical tool. Advantages include speed, extreme sensitivity, permanent photographic record of the analyses, low operating cost and the ability to make simultaneous determinations of many components, including those whose presence may not have been previously suspected. The principal disadvantage is the initial cost and the necessity for considerable preliminary development and standardization of methods and operating conditions.

The inclusion of petrographic and metallographic apparatus indicates increasing interest in pipe corrosion and incrustation problems. The use of photomicrographic equipment demonstrates interest in biochemical control and research. Further evidence of research is found in the fact that nineteen laboratories do their own glass blowing and in the increasing interest in microchemical tests, polarigraphic methods and radioactivity.

Although it is gratifying that advances have been made, it is a somewhat sobering thought that this supplemental or specialized equipment is concentrated in only a few laboratories. Actually the majority of water laboratories are under-equipped and their personnel is carrying on investigation and research in spite of inadequate equipment. Water quality control is a highly technical and specialized subject and it is becoming increasingly apparent, and rightfully so, that water laboratories should conduct research and provide limited service relating to water problems. The increased importance and knowledge of corrosion and incrustation problems, cross-connections, biological control, boiler-scale and other industrial problems indicate an increasing need for pH meters, conductivity, metallographic, petrographic, photomicrographic, spectrophotometric and spectrographic equipment.

Analytical Questionnaire

The scope of the questionnaire on analytical methods (see summary, Table 2) was limited primarily to procedures which have been developed since the 1936 edition of *Standard Methods for the Examination of Water and Sewage* (3) and to those which appear to be controversial. Thus, methods for calcium, chloride, copper, etc., were not investigated because it was assumed, from the lack of contrary evidence, that the present procedures were satisfactory or that technics improving on those now popular have not, as yet, been developed. When a laboratory reported the use of two or more methods, all were included in the summary. This accounts for the fact that the total number of methods used always exceeds the number of laboratories making that particular determination.

It should be kept in mind that most water laboratories will normally use the methods set forth in *Standard Methods* because of legal considerations and because of the inherent prestige of these methods which reflect study and analysis by qualified committees. Therefore, the use of other methods may reflect dissatisfaction with the standard methods or may indicate that the alternate methods will give the desired information either with greater accuracy or with a saving of time and materials. In any event, when another method is used by any of the leading laboratories, it is worthy of consideration and its multiple use justifies examination by those who have not already investigated.

TABLE 2

Summary of Analytical Methods Used by 41 Water Laboratories

EXPRESSION OF RESULTS	41
Parts per million	40
Grains per gallon	16
Milliequivalents per liter	13
Equivalents per million	7
Parts per million as $CaCO_3$	1

TOTAL DISSOLVED SOLIDS	41
Drying at 103°C. (*Standard Methods*)	33
Estimated from specific conductance	15
Calculated from sum of cations and anions plus silica	9
Drying at 180°C.—Ind. Eng. Chem.—Anal. Ed., **5**: 4 (1933)	5
Converted to and weighed as sulfates	2
Drying at 105°C.–110°C.	1

TOTAL HARDNESS	41
Soap method (*Standard Methods*)	28
Calculated from calcium and magnesium results	28
Motorized method of Langelier—Jour. A.W.W.A., **32**: 279 (1940)	7
Titration with potassium palmitate	6
Soda reagent method	4
U.S.G.S.—modified soap method	1
Motorized method—Dr. Hale's modification	1
Brown—Villarruz soap method—Jour. A.W.W.A., **30**: 1021 (1938)	1

ALKALINITY	40
By titration using methyl orange indicator (*Standard Methods*)	35
By titration using bromocresol green-methyl red indicator—Ind. Eng. Chem.—Anal. Ed., **13**: 466 (1941)	8
By electrometric titration	8
By titration using methyl red indicator	4

CARBONATE EQUILIBRIA (CO_2, OH, CO_3, HCO_3)	40
By titration (*Standard Methods*)	29
By computation, tables or graphs from total alkalinity and pH results	20
Carbon dioxide by absorption—CO_3, HCO_3 and OH (*Standard Methods*)	2
Carbon dioxide by titration after fixation with marble chips, CO_3, HCO_3 and OH by titration using phenolphthalein, methyl red and air	1

SATURATION INDEX	31
Calculated or from charts, graphs, slide rule, etc., based on Langelier's tables	22
By actual saturation of sample with $CaCO_3$	16
Enslow apparatus	1

ALUMINUM	31
Precipitation as $Al(OH)_3$ and ignition (*Standard Methods*)	21
Colorimetric with hematoxylin	16
Colorimetric with Alizarin S	2
Spectrographic	2

SODIUM	37
Calculated as sodium and potassium from difference between determined anions and cations and reported as sodium	24
By separation with potassium as the mixed chlorides, determination of potassium as platinic chloride or equivalent metallic platinum and calculation of sodium by difference (*Standard Methods*)	11

TABLE 2—*Continued*

SODIUM—*Continued*	
By separation with potassium as the mixed chloride, determination of potassium as the perchlorate and calculation of sodium by difference (*Standard Methods*)	4
Gravimetric determination as sodium zinc uranyl acetate	9
POTASSIUM	19
By separation with sodium as the mixed chlorides and subsequent determination of potassium as the platinic chloride or equivalent metallic platinum (*Standard Methods*)	13
By separation with sodium as the mixed chlorides and subsequent determination of potassium as the perchlorate (*Standard Methods*)	4
Precipitation as the cobaltinitrite and titration with ferrous sulfate and ceric sulfate—Ind. Eng. Chem.—Anal. Ed., **10**: 652 (1938)	3
Gravimetric determination as the cobaltinitrite—Ind. Eng. Chem.—Anal. Ed., **9**: 136 (1937)	2
Sherrill Centrifuge Method (Precipitation as cobaltinitrite in special tubes. Estimated by volume as compared to standards)	1
Spectrographic	1
CHLORINE	38
Colorimetric with ortho-tolidine	38
Iodometric	3
Colorimetric with *p*-aminodimethylaniline—Jour. A.W.W.A., **35**: 427 (1943)	2
Glass electrode meter	1
Method of Laux—Jour. A.W.W.A., **32**: 1027 (1940)	1
Method of Laux-Nickel—Jour. A.W.W.A., **34**: 1785 (1942)	1
Method of Hallinan—Jour. A.W.W.A., **36**: 296 (1944)	1
SULFIDES	33
Titration with iodine	20
Pomeroy methylene blue method—Jour. A.W.W.A., **33**: 943 (1941)	8
Colorimetric with antimony potassium tartrate	7
Precipitation as ZnS and titration	2
Fixation with CdCl$_2$ and titration	2
Methylene blue method after precipitation as ZnS	1
ARSENIC	23
Gutzeit method	19
Colorimetric method of Jacobs and Nagler—Ind. Eng. Chem.—Anal. Ed., **14**: 442 (1942)	3
Colorimetric method of Chaney and Magnusun—Ind. Eng. Chem.—Anal. Ed., **12**: 691 (1940)	1
Spectrographic	1
FLUORIDE	32
Colorimetric method of Elvove (*Standard Methods*)	4
Colorimetric method of Scott-Sanchis—A.W.W.A. Committee Report—Jour. A.W.W.A., **33**: 1965 (1941)	25
Colorimetric method of Lamar and Seigmiller—Ind. Eng. Chem.—Anal. Ed., **13**: 901 (1941)	2
Method of Willard and Winter—Ind. Eng. Chem.—Anal. Ed., **5**: 7 (1933)	1
Sanchis method—Ind. Eng. Chem.—Anal. Ed., **6**: 134 (1934)	1
Method of Talvitie—Ind. Eng. Chem.—Anal. Ed., **15**: 620 (1943)	1
LEAD	26
Colorimetric as sulfide (*Standard Methods*)	11
By dithizone	19
Dropping mercury electrode	1
Spectrographic	1

TABLE 2—*Continued*

ZINC	25
Turbidimetric with ferrocyanide (*Standard Methods*)	14
Turbidimetric with diethyldithiocarbamate—Jour. A.W.W.A., **33**: 246 (1941)	9
Dithizone	2
Spectrographic	2
Precipitation as ZnS	1
SULFATES	41
Gravimetric as BaSO₄ (*Standard Methods*)	38
Turbidimetric	13
Titration with tetrahydroxyquinone (T.H.Q.)	4
Benzidine method	1

Expression of Results

Continuing the quest of more than half a century, water chemists are still striving to agree on common terminology for the exchange of information. Inspection of current methods of expressing the results of a water analysis reveals two distinct, divergent and yet understandable trends. First, there is a definite trend in all laboratories toward the use of the term "parts per million" (ppm.) and away from the term "grains per gallon" (gpg.). Results of the questionnaire clearly prove that "ppm." has become the almost unanimous choice of water technicians, and while many continue to supplement their reports with results calculated as "gpg.," this practice is admitted to be because of tradition rather than choice. The "ppm." has the advantage of being convenient for measuring the gross amount of material in water, is an easily understandable unit, and its constant use facilitates comparisons with results published in the literature of the field.

The second trend is the attempt to standardize on a term which reflects true stoichiometric relationship and can be used for balancing analyses, for facilitating calculations in water treatment problems and for presenting results graphically. Unfortunately, this second trend, although holding the center of interest, appears to be deteriorating in so far as practical results are concerned. The two leading methods of stoichiometric expression are milliequivalents per liter (mE/l.) and equivalents per million grams (epm.). The thirteen-to-seven lead held by the term "mE/l." in the summary is somewhat misleading, as "mE/l." is older, better established and recommended by *Standard Methods*,*

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* The following statement by Langlier (Jour. A.W.W.A., **34**: 335 (1942)) epitomizes the attitude of the editors of *Standard Methods*: "The unit 'equivalents per million grams' (epm.), tentatively approved by the American Society for Testing Materials in 1940, appears to be more consistent when used together with the firmly established 'parts per million' (ppm.), because each is a 'weight per weight' unit. The abbreviation (epm.), however, introduces a serious inconsistency in that the letter *m* stands for 'million grams' rather than for 'million equivalents' as might be inferred from its significance in the term (ppm.). Because of this, and also because, in the use of weight per weight units, it is not always clear whether weights of *solution* or weights of *solvent* is meant, the authors prefer to use the weight per volume units, i.e., milligrams per liter (mg./l.) and milligram equivalents per liter (mE/l.). Each of these is consistent with the other, and, in the case of saline waters, there can be no uncertainty as to whether or not a specific gravity correction has been applied."

TABLE 3
Suggested Group Determinations

	Mineral Analyses	Sanitary Analyses	Public Health Standards	Corrosion	Industrial Analyses	Agricultural Analyses	Distribution Quality	Biological Correlation Studies	Suspected Organic Pollution	Determination of Source
Specific Conductance	x			x	x	x		x	o	x
Dissolved Solids (103°C.)			x							
Calcium (Ca)	x		x	x				x		
Magnesium (Mg)	x		x							
Palmitate Hardness					x	x				o
Potassium (K)	x					o				
Sodium (Na)	x					x				
Percentage Sodium						x				
Alkalinity (CaCO₃)	x		x	x	x	x		x		o
Chlorides (Cl)	x	o	x		x	x			o	o
Sulfates (SO₄)	x		x		x	x				o
Nitrate (NO₃)	x	x			o	x		o		
Temperature				x	o		x	x		
pH	o		o	x	x		o	x		
Carbon Dioxide (CO₂)	o			x			o	x	o	
Saturation Index				x			o			
Silica (SiO₂)	x			o	o			o		
Iron (Fe)	x		x	o	o		o	o		
Manganese (Mn)	o		x		o		o	o		
Aluminum (Al)	o									
Arsenic (As)			x							
Boron (B)	o					x				o
Chromium (Cr)			x							
Copper (Cu)			x					o		
Fluoride (F)	o		x							o
Lead (Pb)			x							
Selenium (Se)			x							
Zinc (Zn)			x	o						
Phenols		o	o						o	
Phosphates (PO₄)	o					o		o		
Sulfides (S)		o	o				o	o	o	
Color		x	x				x			o
Odor		x	x				x		o	o
Turbidity		x	x				x			
Oxygen Consumed		x					o		o	
Dissolved Oxygen		x		x			x	o	o	
B.O.D.		x					o		o	
Ammonia (NH₃)		x					o	o	x	
Nitrites (NO₂)		x					o		x	
Albuminoid Nitrogen		o								
Organic Nitrogen		x					o		o	
Free Chlorine (Cl₂)		o	x				o	o		o

NOTE: x Determinations usually made.
      o Supplementary tests, of value under certain conditions.

whereas "epm." has but recently come into prominence (4). Actually, the fact that it is already being used by seven laboratories indicates a definite trend in its favor. From a practical laboratory standpoint either method should be acceptable.

An insight into the problem of achieving a mutual understanding in this field may be obtained by examining the latest recommendation by various organizations interested in water chemistry. The recommendation of the *Manual of the Railway Engineering Association* is "gpg." (1932); joint American Public Health Association and the American Water Works Association, "ppm." and "mE/l." (1936); Association of Official Agricultural Chemists, "mg./l." (1940); American Society for Testing Materials, "ppm." and "epm." (1940); American Society of Mechanical Engineers, "ppm." and "gpg." (1943); Water and Sewage Unit, Repairs and Utilities Branch, Construction Division, Office of Chief Engineer, War Department, "ppm." and "epm." (1943).

It is unfortunate that all organizations interested in water analysis cannot get together and adopt a joint standard. The confusion caused by the present inconsistent terminology, due in part to stubborn defense of each method, is not a healthy condition for the interchange of information between the various organizations.

Specialized Analyses

The trend toward specialization in water analyses is readily apparent in the tables. The typical old-style analysis, which covered total solids, silica, iron and aluminum oxides, calcium, magnesium, alkalinity, chlorides, sulfates and sodium by difference, is no longer adequate. For example, such an analysis will not tell whether a water may cause mottled teeth, whether it is potentially corrosive, or whether it can be safely used for irrigation of citrus trees. A specialized analysis, in addition to giving the required information, will save time and material, as fewer determinations are usually required to secure the desired information. A laboratory guide showing determinations usually run in the Los Angeles Sanitary Engineering Division laboratory is shown in Table 3. Individual circumstances will of course alter recommended determinations.

Complete Mineral Analyses

Recent developments in analytical technics have enabled chemists to report complete mineral analyses with greater accuracy and confidence than has heretofore been possible. In the past, complete analyses have not always been satisfactory due to the traditional practice of calculating the amount of sodium and potassium from the difference between the total determined cations and anions and reporting the result as sodium. In addition to the inherent error present in any determination by difference, significant quantities of nitrates and other anions were often missed, which caused low results for the alkalis. Even when sodium and potassium were laboriously determined, major compensating errors in balancing the sums of cations and anions were difficult to detect. Improved technics for determining sodium, potassium and conductance now make it possible to check the actual conductance of the sample with the calculated conductance of all the determined ions, in addition to checking the stoichiometric equivalents of the cations and anions.

Wartime Pollution

Although not readily discernible from the summary, wartime conditions have greatly stimulated interest in the development of tests for the detection of pollution due to enemy activities, either deliberate or accidental. Goudey (5) has recommended that laboratories be on the alert for arsenical compounds, heavy metals, cyanides, phenolic derivatives, alkaloids and war gases and has suggested methods for their determination. He points out the significance of abnormal variations in odor, chlorides, sulfates, nitrates, B.O.D., oxygen consumed, pH and chlorine demand and he recommends routine methods for the detection of pollution. Buswell et al. (6) have proposed methods for distinguishing between different war gases by differential titration of excess chlorine at different pH values.

Current Standards Inadequate

A study of the summary also reveals that the traditional retention of obsolete methods will retard the adoption of newer technics by many laboratories; conversely, an encouraging proportion of the reporting laboratories do not feel tied down by the *Standards* and do not hesitate to use new methods which they consider to be superior. The latter are the leaders in their specialized field and any proposed changes in the current *Standard Methods* should take advantage of the knowledge and experience of these laboratories. The Joint Editorial Committee is presumably well aware of this situation and it can be assumed that from their review of current literature and from extensive laboratory investigation there will emerge the most suitable methods for inclusion in our future standards.

Comment on Methods

In order to assist in evaluating the summary of the analytical questionnaire and to facilitate the study and investigation of any procedure, a brief summary of the current status of each individual determination follows:

Total Dissolved Solids

The limitations of determining dissolved solids by evaporation methods are well known and accepted as inevitable. This has resulted in increasing interest in the estimation of dissolved solids by electrical conductivity. Twenty of the reporting laboratories use this method. Scofield and Wilcox (7) first showed that a definite relationship existed between the specific conductance and the dissolved solids in a water and that the solids could be estimated by multiplying the conductance by an appropriate factor which depended on the predominate anions. Kitto (8) prepared empirical curves plotting total dissolved solids against the conductance of synthetic salt solutions and determined the solids from the specific conductance and the results of the CO_3, SO_4, Cl and NO_3 analysis. Sokoloff (9), in a study of several thousand irrigation waters, found that variations in the ratio of either anions or cations to the specific conductance were primarily affected by the ratio of sodium to total cations, the ratio of chloride to total anions, and the total concentration of electrolytes. Using these observations as a basis, he presented a means of checking the accuracy of a complete analysis, and of calculating the sum of calcium and magnesium based on three determinations, namely, conductance, sodium and chloride. Gustafson and Behrman (10) have shown that specific conduct-

ance can be more than a rough empirical index. Recognizing that conductivity is a definite function of and varies with the individual ions, they have proposed a method of checking the determined conductivity with the calculated conductivity. The procedure is applicable to all different types of water ordinarily encountered and the accuracy is comparable to that of other routine analytical methods.

Hardness

While conceding that calculation from calcium and magnesium results is the most accurate method, the trend in determining hardness is toward refinements of the standard soap procedure designed to improve accuracy without sacrificing speed. Proposed variations seem innumerable and five are reported in the summary.

Alkalinity

Even the "old reliable" methyl orange titration for total alkalinity has recently been under fire. In addition to the recognized difficulty of perceiving the color change at the end-point, its accuracy in waters of low alkalinity has been seriously questioned. Cooper (11) has shown that the pH at the equivalence point in very dilute carbonate solutions is a function of the residual carbonic acid and that, for waters containing less than 1.2 millimoles per liter, high results will be obtained when methyl orange is used. He suggests the use of bromocresol green-methyl red indicator and proposes a method whereby the pH values to be obtained at the final end-point can be ascertained before that point is reached and thus allow the selection of the proper indicator color.

In order to check Cooper's findings as applied to Los Angeles waters, a series of electrometric titrations were made on samples of varying alkalinity, and the true equivalence points were compared with the methyl orange and bromocresol green-methyl red endpoints. The error using methyl orange was found to be negligible with waters low in free carbon dioxide and containing over 80 ppm. alkalinity (CaCO₃). With lower alkalinity, however, the error became appreciable, and a mountain source having an alkalinity of 20 ppm. showed a plus error of 8 per cent. Using bromocresol green-methyl red it was possible to titrate to the true equivalence point which occurred at a pH of 5.0. Titrating to this higher pH value also reduced the inherent positive error due to the buffer capacity of pure water.

In spite of the advantages of the bromocresol green-methyl red indicator, it is probable that methyl orange will continue to be used with waters having an equivalence point in the pH range of 4.4–4.7 because from a practical standpoint the advantage of being able to continue the chloride determination without marked interference from the alkalinity titration indicator outweighs the advantages of the newer indicator. Bromocresol green-methyl red indicator should be favored when chlorides are not to be determined and with waters of very low carbonate content.

Carbonate Equilibria

A definite trend toward the mathematical approach to carbonate equilibria problems is confirmed by 20 of the reporting laboratories. Recent investigators (11, 12, 13) applying mass action relations to carbonate equilibria in water supplies have shown inherent errors in the titration method. DeMartini's (14) equations have made

possible the calculation of the carbon dioxide, normal carbonate and hydroxide from the pH and total alkalinity results. Moore (15) and Dye (16) have presented these equations as graphs and nomographs, and Hirsch (17) has simplified calculation of the relationship by means of a slide rule.

Saturation Index

Langelier's 1936 paper (18) on anticorrosion water treatment stimulated widespread interest in the theoretical aspects of calcium carbonate deposition. Correlation of the theoretical approach with practical field observations has proven valuable in corrosion and incrustation control. Hoover (19), Larson and Buswell (20) and Hirsch (21, 22) have contributed to the practical application of Langelier's tables by the introduction of a graph and nomograms, minor corrections and additions, and special slide rule and scalar diagram for facilitating calculations.

Aluminum

The trend in determining aluminum continues toward colorimetric procedures. Sixteen reporting laboratories use the hematoxylin procedure and two employ the Alizarin S reagent. The present practice of listing a gravimetric procedure as the standard method and a colorimetric method as a non-standard method is regrettable, as this results in many laboratories using the gravimetric method when it is actually not suitable for the water being analyzed. Confirmation of this statement is readily obtained by inspection of the current literature. Innumerable analyses show high results entirely incompatible with the complete analyses. The water technician cannot be entirely blamed for this situation as he

has faithfully followed *Standard Methods* to obtain his results. In addition, many laboratories realize the inherent inaccuracy of the method but justify its use because it is the standard method and because if they abruptly changed to the more suitable colorimetric procedure it would be embarrassing to explain the discrepancy to those who regularly reviewed their reports. This is a most unsatisfactory condition which could be corrected by the adoption of a sensitive colorimetric procedure as the standard. If it were felt necessary, the gravimetric method could be referred to as suitable for unusual waters, although in the actual determination of aluminum in hundreds of southwestern waters only one sample has been encountered when the gravimetric procedure would be more accurate than the colorimetric. This water was from a volcanic hot spring and even in this isolated case satisfactory colorimetric results could be obtained by dilution of the original sample.

Sodium and Potassium

The fact that 24 reporting laboratories resort to the determination of the alkalis by calculation testifies to the complexity and inaccuracy of the present procedures. The questionnaire shows a strong trend toward the use of the zinc uranyl acetate reagent for sodium and the increasing use of some variation of the cobaltinitrite method for potassium. The problems pertinent to the sodium and potassium determination are in many respects similar to those of aluminum. These sections of *Standard Methods* have not been materially changed for six editions and the current methods are entirely inadequate.

Free Chlorine

Current investigation of methods for the determination of free chlorine is confined primarily to refinements in the ortho-tolidine procedure. Methods have been proposed by the A.W.W.A. Committee on Control of Chlorination (23) which reduce present interference, measure both high and low residuals in the field as well as in the laboratory, determine chlorine demand under variable conditions and differentiate between chlorine and chloramine. Major recommendations include the use of ortho-tolidine dihydrochloride instead of ortho-tolidine because of the greater purity of the commercial product, a change in acid ratio of the ortho-tolidine reagent, the use of the modified Scott chromate-dichromate permanent standards and the use of the iodometric method for determining higher chlorine residuals.

Sulfides

The choice of methods for determining sulfides appears to be dependent on the concentration of sulfide present and on the accuracy required. When the concentration exceeds 1.0 ppm., the iodometric technic is the most accurate and is generally in favor with the reporting laboratories. As concentrations decrease, however, any blank due to iodine-consuming compounds other than H_2S will become of increasing magnitude and casts serious doubts on the quantitative or even the qualitative accuracy. The Antimony Tartrate procedure is fairly satisfactory in concentrations of from 0.1 to 5.0 ppm. The results cannot be considered truly quantitative, as the accuracy is limited by the variable color, turbidity and degree of dispersion of the antimony sulfide precipitate. This method, however, is simple and practically foolproof, since a precipitate will form under a wide variety of conditions and is satisfactory when only semi-quantitative results are required. The methylene blue technic is the most sensitive and accurate in low concentrations and is suitable for concentrations of from 0.01 to 5.0 ppm. It is the only satisfactory method for the estimation of traces of hydrogen sulfide such as are encountered in dead-ends and in the lower levels of stratified reservoirs.

Arsenic

The preponderance of laboratories using the Gutzeit method for arsenic is due in part to tradition and in part to the simplicity of this technic. If arsenic is present in significant amounts, however, methods employing the molybdenum blue reaction are to be preferred, as they have superior accuracy and sensitivity. Either the Jacobs and Nagler technic (which, together with the Gutzeit method, has recently been recommended by the Advisory Committee on the Revision of Drinking Water Standards (24)) or the Chaney and Magnusun procedure is satisfactory.

Miscellaneous Methods

The appreciable majority of laboratories using the Scott-Sanchis (A.W.W.A. Committee Report) method for fluoride and the dithizone technic for lead speaks for itself. The carbamate method for zinc is being adopted by an increasing number of laboratories. It is more sensitive than the standard ferrocyanide procedure and has the additional advantage of having the reagent already prepared in laboratories which use the standard carbamate method for copper.

The standard method of determining sulfates gravimetrically as barium sulfate is one of the older methods which continue to defy all competition. Turbidimetric procedures are possibly superior to the gravimetric procedure in concentrations under 5 ppm., but, due to the non-uniformity of dispersion and grain size, this method gives results which should be considered only rough approximations. Direct titration methods have been found advantageous for boiler and other saline waters but as yet are not sufficiently sensitive for determining the small quantities of sulfates encountered in normal potable waters. Determinations not included in the summary but which appear worthy of investigation are the titan yellow method (25) for magnesium, the diphenylcarbazide method (26) for chromium, and Knudson's et al. (27) modification of the molybdate method for silica. In addition, Kehoe et al. (28), in a survey of trace elements in eastern and central United States, have recently described methods that detect 0.001 mg. per l. of manganese, lead, tin, iron, aluminum, copper, silver, zinc, arsenic and mercury.

Conclusion

1. Physical methods of analysis, stimulated in part by improved laboratory instruments, are replacing many of the traditional chemical procedures. Potentiometers, spectrophotometers and spectrographs, formerly restricted to research, are now finding a place in routine laboratory control.

2. The development of new tests and the increasing knowledge of physiological, biological and industrial relationships have resulted in analyses being streamlined for specific purposes, permitting more pertinent information with economy of time and material.

3. To insure accuracy and confidence in a complete mineral analysis, all cations, including sodium and potassium, should be individually determined and checked against both the total anions and the specific conductance.

4. *Standard Methods for the Examination of Water and Sewage,* due to its infrequent revision and cumulative nature, must necessarily always be in arrears of the latest developments. The results of the analytical questionnaire show certain portions of *Standard Methods* to be inadequate and in need of revision.

5. It is the obligation of progressive water chemists to keep abreast of current progress and to take the initiative in the development, investigation and adoption of new methods and equipment.

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DISCUSSION—*M. C. Schwartz*

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Insofar as Mr. Graham's article points out the newer trends in water analysis and urges the further development of both personnel and equipment in our laboratories, his paper serves a very useful purpose. However, if one of his reasons for writing this paper is to demonstrate that the eighth edition of *Standard Methods* is in need of revision, his article is hardly necessary. The Joint Editorial Committee, as well as a number of individuals, has been aware of this fact for several years and the ninth edition of *Standard Methods* is being prepared for distribution this year. The ninth edition would undoubtedly have appeared much earlier had it not been for the war. It is quite

possible that a preview of the contents of the ninth edition should have appeared in print before now, thereby reassuring those interested that recent developments were under consideration.

The analysis of water and the various deposits arising from contact of water (or steam) with the material conveying the water (or steam) is simply a specialized branch of analytical chemistry. .The last ten years have seen remarkable advances in the general field, particularly toward the use of "instrumental methods." This period practically covers the gap between the eighth and ninth editions of *Standard Methods*.

As Mr. Graham points out, there has been a considerable shift from the chemical methods, as exemplified by gravimetric analysis, to physical-chemical methods, as exemplified by the use of filter photometers or spectrophotometers. This change has been taking place not only in water analysis but in all fields of analytical chemistry. The three types of instruments which have been widely adopted by water laboratories are the electronic pH meters, the filter photometers and spectrophotometers, and the electrolytic conductivity bridges. The spectrograph and the metallographic microscope have had very limited use in the field of water. The polarigraph will undoubtedly have a more widespread application in this field than it is presently receiving. The use of the petrographic microscope and x-ray diffraction analysis equipment is very limited in this field but in some instances it is indispensable. A new type of photometer, called the flame photometer, is now available. Its use, according to the writer's experience, will revolutionize the analysis of sodium and potassium.

In the ninth edition of *Standard Methods* the chapters on "Sanitary and Mineral Analyses" have been consolidated, thus eliminating the artificial distinction and the frequent duplication involved. The number of substances for which methods of analysis are given has been increased and the scope of the methods of analysis for a given substance has also been increased to include other methods beside gravimetric methods. There is a tendency in making a widespread revision to throw out old standards. A gradual transition in this direction is better since *Standard Methods* must show a reasonable amount of conservatism and let some of the newer methods prove themselves.

One particular point that seems to justify some discussion is the apparent desire of some to discard gravimetric methods entirely. This idea, I believe, is unsound. For example, in the determination of very small amounts of aluminum, it is admitted a good colorimetric method will be more satisfactory than a gravimetric method. However, the colorimetric method must at some time be standardized against known solutions of aluminum whose analysis will be made by gravimetric methods.

One fundamental problem in water analysis consists of the identification of compounds formed by evaporation of water. For years we have been using various schemes of hypothetical combinations. We do have available the petrographic microscope and the x-ray diffraction analysis equipment for direct identification of these compounds. Excellent results are being obtained from their application.

Determination of sodium and potassium has also been a sore spot in water analysis for many years. Some

of the newer methods of determining sodium and potassium are included in the ninth edition. The use of the flame photometer, however, is not covered because of its extreme newness. However, it appears to be the coming method.

It would be out of place to present a more detailed analysis of the contents of the ninth edition in a discussion of this paper, particularly in view of the fact that the book is scheduled to appear this year. Mr. Graham's interest and desire to use the latest developments in the field of analytical chemistry is very commendable. The most satisfactory way of meeting the desires and demands of such people is to revise *Standard Methods* more frequently.

DISCUSSION—*Harry E. Jordan*

The Los Angeles Department of Water and Power has provided for the control of water quality in its service area a competent sanitary engineering and laboratory staff and the most adequate equipment for the work to be done. Mr. Graham, as the department's Chief Chemist, is entitled to full consideration of the opinions which he records. The survey of practice in American water control laboratories which he has made is of great value and executives who deal with policy-making in water control laboratories should give heed to the ideas which this article offers.

Mr. Graham gives some attention to the merits as well as the deficiencies of *Standard Methods for the Examination of Water and Sewage*. Dissent is the privilege, in fact the obligation, of technical and professional men. The writer has been a dissenter re *Standard Methods* at times. He was later Chairman of the Joint Editorial Committee which prepared the eighth (current) edition. No informed person will deny that the ninth edition is technically long past due. But it is of interest to note that, as the ninth edition moves towards completion, certain very important procedures are still the subject of much debate and some dissent —even as they go into print.

The JOURNAL has been the medium of presentation of many articles concerning water examination methods, which later have been accepted by the editors of *Standard Methods*. The very first formal article in Vol. 1, No. 1 (March 1914) of this JOURNAL expressed dissent with the 1912 edition of *Standard Methods* in its substitution of the plate count on agar for the plate count on gelatin and the change in incubation time and temperature from 48 hours at 20°C. to 24 hours at 37°C. There is no doubt that when the ninth edition appears, someone will object to the methods for bacteriological examination therein contained and, in all probability, the JOURNAL will print articles which discuss the subject.

Quite a while ago the writer reached the opinion that a standard text cannot be a daring or exploratory text. Daring and exploration belong to individuals, not to standards. A standard method must be one which has long since passed the stage of publication of the original article about it. The method must have been tried by those competent to appraise it objectively (the original author rarely is)

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and by those who are not so competent but who need precise, foolproof direction and who, even with their limited ability, are able to apply the method in the control of water purification or production. When a method has had this type of seasoning and it serves a need in the appraisal of water quality, it earns its way into *Standard Methods*.

The very background of *Standard Methods* makes its preparation laborious. A single author could write such a text with the greatest of ease—if the author were competent. A committee of a single association could work with considerable ease and speed, provided that the association did not set up too much "procedure" to control the committee. But *Standard Methods* is a two-association sponsored document, with a long tradition and much protocol behind it. The committee which edits the text must discuss its proposals with various interested groups in each association. It likewise attempts fully to take into account the opinions and suggestions of other groups in other associations competently interested in the subject matter. And when a new edition appears, it will contain some mistakes of judgment and some methods which, in the opinion of part of its clientele, are obsolescent when the text appears. But nowhere else in the world has there been a manual comparable to it—the product of a combination of professional democracy and representative action, always behind the experimentalists, it remains the accepted and safe guide to the many thousands of earnest workers who control water quality and protect the public health by their devotion to duty.

Development and Practice of Municipal Water Softening

By H. M. Olson

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A contribution to the Journal

THE first municipal water softening plants were installed at Southampton and Canterbury, England, in 1888. North America's first plant was installed at Winnipeg, Canada, in 1901, and the first in the United States was placed in operation at Oberlin, Ohio, in 1904. St. Louis, Mo., also in 1904, introduced lime softening and a similar plant was installed at Columbus, Ohio, in 1908.

The largest population now served with a softened supply is at Ventura, Calif., from which over 2,000,000 people in twelve communities receive water from a combination lime-soda-ash-zeolite plant treating water from Boulder Dam, Colo. The smallest community served is Cameo, W.Va., where a zeolite system furnishes soft water to a population of 100. A Spaulding Precipitator at the 120-mil. gal. sludge-blanket type plant at Minneapolis, Minn., softens Mississippi River water for 429,000 people who, in 1939, used an average of 50 and a maximum of 104 mgd. of water. At Kansas City, Mo., the old filtration plant, using Missouri River water, was converted to a softening plant with a capacity of 150 mgd., without additional operating cost.

There were 576 municipal water softening plants in operation as of Dec. 1, 1941 (1). In a later survey made by the author (2) it was shown that as of Jan. 1, 1945, there were 665 softening plants in the United States, representing a gain of 89 plants in approximately three years' time. These plants serve 900 communities with a total population of about 12,000,000. In addition there are from 400,000 to 450,000 privately-owned domestic softener units in operation. About 350 communities in 25 states have soft water service, either privately or municipally operated, with 200 regenerating stations in which approximately 105,000 units with from 190,000 to 210,000 regenerations per month are used. Florida had only one such system operating in November 1944. In Indiana, as of Jan. 1, 1945, there were twelve communities with this service, using 10,000 regenerations per month and softening 15 mil.gal. of water to zero hardness. Rockford, Ill., has 2,600 units with 8,000 regenerations per month and Canton, Ohio, has 1,600 units with 2,400 regenerations per month. The latter two systems are both privately operated.

Over 69 per cent of all the municipal water softeners are installed in the so-called hard water area of the United States, which includes Wisconsin, Illinois, Michigan, Indiana, Ohio and surrounding states. Ohio alone had 127 plants as of Jan. 1, 1945.

Some of the larger cities in the hard water area that are contemplating water softening are Louisville, Ky.; Davenport, Iowa; Dayton, Springfield and Zanesville, Ohio; and Freeport, Ill.

Chicago's South Side Filtration plant, which is now approaching completion, and the recently completed filtration plant at Milwaukee, Wis., are so equipped that water softening can be started, with a minimum expenditure, on the Lake Michigan supply which has a hardness of approximately 128 ppm.

In general the following phrases describe varying degrees of hardness:

Soft—Hardness of less than 50 ppm.

Moderately Hard—Hardness between 50 and 150 ppm.

Hard—Hardness between 150 and 300 ppm.

Very Hard—Hardness over 300 ppm.

Hardness, however, is only relative. Persons living in Miami when the water was not softened (290 ppm.) thought when they were in Chicago, for instance, that the water was soft at 135-ppm. hardness. Chicago residents, on the other hand, think that New York City water at 33 ppm. is soft and the people of New York City think that the waters in some of the mountainous sections of New England and Pennsylvania are soft at 17 ppm., and so it is all over the country.

When municipal softening was first started the distributed water was considered satisfactory at 100-ppm. hardness but now the general practice is to reduce the hardness to 65 ppm. Under some conditions, depending on whether the corrosive tendencies in the distributed supply can be properly controlled to correct red water troubles, a 50-ppm. supply has been found satisfactory.

Methods of Obtaining Soft Water

Soft water may be obtained in the following ways:

1. Year-round collection of water from "soft water" watershed areas into reservoirs, as is done for the New York City water supply and which is now being contemplated for the Pittsburgh area.

2. Collection of "soft water" runoff from watersheds, streams, rivers, etc., during those periods of the year when the supply is soft, as is the practice at Oklahoma City, Okla., and Morgantown, W.Va.

3. Collection of rain water in cisterns.

4. Domestic water softeners, available only since zeolite water softeners came into use about 1914.

5. Softening with soap and chemicals aided by heating.

6. Soft water service—domestic and commercial—consisting of the installation of small zeolite units that are periodically regenerated at a central plant.

7. Evaporating and condensing water to and from steam—a very expensive process.

8. Central water softening plants for the entire city supply.

There are two plans now possible for softening a municipal water supply, both of which will give good results if properly operated: (1) The entire municipal supply is softened to around 120 ppm. with chemical control balance in the water. In addition to this, a soft water service may be provided for those who wish to pay an extra charge for water softened to zero hardness. (2) The water at the central plant is softened to 50 ppm. A water of this hardness content has been found satisfactory in most cases but the im-

portant thing is to maintain a proper chemical balance. The economics involved in each case should be studied to determine which method is better for the conditions prevailing.

There are two general methods of water softening now employed: (1) chemical precipitation and (2) zeolite or base exchange. Occasionally a combination of these methods is used. These methods do not include forms of water *conditioning* for the removal of iron, manganese, gases, etc. It must be borne in mind, however, that in a great many instances, by the use of additional chemicals and proper control of operations, some or all of these nuisances can be removed at the same time and with the same equipment as is needed for softening.

Chemical Precipitation

The development of chemical precipitation in recent years has been marked. Certain chemicals, usually lime, soda ash, caustic soda, etc., depending on the raw water characteristics and final quality desired, are added to the water supply in direct proportion to the flow. The chemicals are mixed, settled, filtered, recarbonated and corrected for corrosion stabilization. This process results in a reduction of the total solids content of the water.

There are several different types of design used in chemical precipitation plants. They are:

(1) Old conventional type with single basins of different shapes—circular, square, oblong and variations—and different depths, depending on the designer and previous experiences. This type requires from eight to 144 hours' settling time.

(2) New conventional type with premixing, presettling, dual basins, flocculators and separate recarbonation, etc.

(3) Sludge blanket type where sludge or slurry may be recirculated. Generally from three-fourths to one and one-half hours' detention time is required, depending on the water characteristics and the formation of the sludge.

(4) Contact type where the precipitation depends on a catalyst or granule. The time of actual precipitation is about three minutes; designed detention time is usually fifteen minutes.

(5) Combinations of the above types.

Sand or anthracite coal (Anthrafilt) filters are used with this type of equipment, which includes proper apparatus for control and operations. It has been suggested, however, that the contact type unit could be used to remove the calcium and the sludge blanket unit (arranged in series) to remove the magnesium without the use of a filter.

Zeolite or Base Exchange

The term "zeolite" is applied to a class of alumino-silicates which contain readily replaceable ions such as sodium and potassium. When added to water the zeolite takes up the calcium and magnesium ions (which constitute hardness in water) and gives up in exchange replaceable sodium or potassium ions. The total solids content remains unchanged.

When the non-hardening ions have been depleted the softening capacity of the zeolite is restored by regenerating with a solution of common salt.

Control is usually obtained (1) manually, hydraulically, electrically or hydraulically-automatically in operation or (2) by means of cation and anion exchangers using salt, alkali and acid

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as regenerants or stabilizers that will remove all the insoluble and soluble salts in a water, making it as good as, if not better than, distilled water.

In base-exchange operations the following kinds of exchange minerals are used: natural greensand, high-capacity greensand, synthetic silica gel, refined bentonitic clay, and carbonaceous and resinous zeolites.

All of the above types can be regenerated with salt brine but the carbonaceous and resinous zeolites can also be regenerated with acids and alkalis.

Developments are rapid in this field and other types of minerals no doubt will soon be on the market. Experiments have been made with bituminous coal wastes to obtain at a small cost a base-exchange mineral that will be good for one or just a few regenerations.

In operating a base-exchange softener the mineral is placed in a container, of gravity or pressure type, which is supported on layers of gravel similar to those used in sand filter design. The incoming water is passed either downward or upward through the granular zeolite bed at certain definite rates of flow. The hardness ions in the water are exchanged for the insoluble sodium ions of the zeolite, thus making the water soft but retaining the total solids content.

When a particular unit has exhausted its base-exchange capacity, it is ready for regeneration. The length of the period between regenerations depends on the type of mineral used, the total amount of raw water flowing through, hardness, rate of flow, the total solids, etc. To regenerate, the softener is backwashed for about ten minutes, the exact period depending on the condition of the backwash water used. Then

a predetermined amount of salt brine is distributed evenly over the top of the zeolite bed and passed down through it, reacting with the zeolite to remove the calcium, magnesium, ferrous iron and manganous manganese and at the same time restoring the zeolite to its original condition. The amount of salt is determined in proportion to the exchange capacity and the cubic feet of mineral in the bed and varies with each type of mineral and form of operation —from 0.35 lb. per 17,100 ppm. hardness as $CaCO_3$ removed with the synthetic gel zeolites to 0.55 lb. per 17,100 ppm. for the bentonitic zeolite types.

The last step in the regeneration process is the salt rinse, which consists of washing the calcium and magnesium and excess salt to the sewer outlet by means of a slow flow of water through the bed. The rate of flow depends on the type of mineral, the depth of the bed, etc., and the time usually required is from 20 to 25 minutes with greensand to 65 minutes for some types of gravity-operated synthetics. After the rinse the softener is returned to service.

The electric cell method of softening, which requires low cost electric power, is now being developed and may be used in future softening operations. As yet, however, no plants in the installation stage are yet in operation.

Avoiding Red Water Troubles

With the chemical precipitation type of equipment the water is softened to a definite hardness, as required or as predetermined, and is then conditioned for distribution. With the zeolite type of softening, the raw water is softened to zero hardness, and then a part of it is properly treated and bypassed to obtain the predetermined hardness in the distributed supply.

In order to be free from red water troubles it is necessary to stabilize or inhibit the water in the distribution system. This may be done by recarbonating the chemically precipitated water or adding lime to condition with sodium hexametaphosphate. In the zeolite system it is necessary to add either soda ash, caustic soda, caustic soda and sodium silicate or sodium hexametaphosphate to maintain the proper calcium carbonate stability. This is usually at a pH of about 7.9–8.0 on a distributed supply of from 65- to 85-ppm. hardness.

There are only two combination chemical precipitation-zeolite plants operating on municipal supplies at the present time; one is at LaGrange, Ill., the other at Ventura, Calif. There is one Spiractor at Teutopolis, Ill.; one brine-well-zeolite system at Westview, Pa. (suburb of Pittsburgh); and one sea water regenerated zeolite system at Sarasota, Fla.

At LaGrange, Ill., where lime pretreatment, reducing the raw water from 1,060 ppm. to 273 ppm., is followed by an upflow synthetic zeolite process, it was found that the addition of lime or Calgon as a stabilizer did not eliminate red water troubles. Consequently 2 per cent of the raw water was bypassed to provide enough calcium in the distributed water so that soda ash would react to provide the proper pH and calcium carbonate stability.

Benefits From a Softened Supply

The numerous benefits derived from a softened water supply fall into the following categories:

1. Savings in household operations involved in the use of soap and cleaning compounds.

2. Elimination of the cost of installing household water softeners or reduc-

tion in the cost of operation of those already installed.

3. Elimination of separate soft water storage and piping systems.

4. Reduction in the cost of process water for industrial and commercial establishments.

5. Increased revenues of the public utility by virtue of greater sales of water for all purposes in the community.

"Savings in household operations involved in the use of soap and cleaning compounds" will account for approximately one-half of all the savings to be made with a softened water supply. The savings will vary, however, with the hardness of the raw water, the hardness of the distributed supply and the types of industry and homes involved.

In a southern city which has a population of 310,000 served by water softening plants, the raw water has been softened from 297 ppm. to 72 ppm. The estimated cost of soap, based on 1938 prices, would be $6.38 per capita at 297 ppm. and $5.14 per capita at 72 ppm.—a difference of $1.25 per capita or a total savings of approximately $385,000 per year. It is reasonable to expect that the total benefits would represent a saving of from $800,000 to as high as $1,200,000 per year.

A middle western city of 400,000 population with a public supply having a raw water hardness of 250 ppm., would save from $1,000,000 to $1,-250,000 per year by installing a water softening plant which would reduce hardness to 85.5 ppm.

Charles P. Hoover, in a report of the operations of the Columbus, Ohio, water softening plant, stated that if, of the entire supply of that city, where hardness is reduced from an average of 265 ppm. to 87 ppm., only 1 per cent

were used with soap each day, the soap savings effected by softening the whole supply would be about $650,000.

Hoover further states that in Columbus the average family of five uses 175 gpd. of water at a cost of 2.9¢. The average yearly cost of water per family of five is $10.60, with a savings in soap alone of $9.77 per year.

Softening water for cleansing purposes cannot be avoided unless very expensive compounds are used. Ordinarily soap is used in the home as a softening agent but it has little cleansing value or action until it lathers and it will not lather until the hardness salts in the water have been neutralized. Softening with soap is expensive—$0.0075 worth of lime, when properly applied and controlled, will soften as much as $3.00 worth of ordinary soap when used in household operations. It is therefore cheaper to soften the entire city supply at a central source than to do it in the thousands of homes, even though, as Hoover states, only 1 per cent of the water consumed needs to be soft.

Planning a Water Softening System

Those who are interested in the installation of a water softening system for their community should organize themselves and carefully study the community attitude toward the project which they wish to promote. Some opposition may be encountered. As these opposing viewpoints appear during the preliminary study they can be reviewed with engineers and public officials who have conducted similar campaigns in other communities and the lessons that they have learned may be applied to the local situation. Finally, competent speakers may be invited to address public meetings or committees,

by way of insuring a general understanding of the subject.

The next step should be an investigation of ways and means—that is, a study of state laws to see if the necessary expenditures can be made.

When it has been determined that funds can be procured, an engineer should be consulted for advice regarding the type of treatment, the maximum capacity possible with the funds available and similar problems. The engineer should then submit a comprehensive report making specific recommendations on these points and covering costs of construction and operation, provision for future expansion, adjustment to changes in water supply, etc.

The report should be carefully studied. If it is necessary to obtain public approval for the bond issue to finance the construction of the plant, a group of public-spirited citizens, recognized as leaders in the various parts of the community, should band themselves together to promote an affirmative public attitude. When public approval has been obtained for the construction of the softening plant, final plans can be drawn, the contractor's bids solicited and construction begun.

Costs

At this point it becomes necessary to make a careful analysis of installation and operating costs and reserve funds for future contingencies, in order to make sound calculations of returns required. In arriving at the true cost of the plant the following items must be known and totaled: (1) cost of developing community interest; (2) cost of preliminary studies, including visits to other communities; (3) costs incurred in investigating state laws and means of financing the project; (4)

TABLE 1

Cost of Constructing Softening Plants

Location	Type of Plant	Year Installed	Designed Capacity 1,000 gpd.	Raw Water Hardness ppm.	Treated Water Hardness ppm.	Average Consumption 1,000 gpd.	Peak Consumption 1,000 gpd.	Cost of Construction	Remarks
Ambridge, Pa.	Gravity type with filters and greensand softeners	1934	1,800	350	70	1,450	1,800	$60,000	During last two years demands went to 3 mgd. when a great deal of hard water had to be pumped into mains due to undercapacity in the softening plant.
Coraopolis, Pa.	Automatic greensand, pressure type, zeolite system, with manganese zeolite pressure unit for conditioning bypass water	1935	1,500	150–300	60	950	1,279	40,000	Cost included equipment only.
Cuyahoga Falls, Ohio	Gravity filter, synthetic zeolite	1936	4,000	256	63	1,214	1,945	69,000	Cost included fine brick building.
Lake, Wis.	Zeolite (silica gel)	1938	1,150	425	102			1,350,000 (including $550,000 WPA funds)	Complete new system installed, including 200,000-gal. tank on a 150-ft. tower, jail, street cleaning department, etc., all housed in ornamental concrete layout on 5-acre landscaped ground area.
Lancaster, Ohio	Gravity filter and softener layout (silica gel)	1934	3,000	360	85	1,250	2,000	74,000	Cost included handsome brick building and excellent laboratory facilities.
New Philadelphia, Ohio	Gravity type, synthetic zeolite (silica gel)	1935	1,500	400	72	905	1,750	75,000	Zeolite has been installed in a third unit to take care of increase in demand due to war plants and increase in hardness because of drought conditions.
Rittman, Ohio	Pressure zeolite	1935	550	200	65	180	225–385	19,700	Cost included building but not consulting engineer's fee.
Sewickley, Pa.	Gravity type zeolite (greensand)	1929	1,750	210	65	750	1,750	262,000	Cost included building, landscaping and engineer's fees.

cost of surveys and reports by engineers; (5) cost of advertising for bids, total construction costs and extra costs not covered in contractor's bids; (6) special costs of placing the plant in operation, and of initial inspections or surveys which are not a part of the regular operating costs.

In addition to the foregoing analysis to establish the actual cost of constructing and developing the plant, operating costs should be computed with the greatest possible accuracy. It is desirable to include in such computations all chemicals and materials used, maintenance, labor, depreciation, supervi-

TABLE 2

Cost of Chemicals

Location	Type of Plant*	Amount of Water Treated mgd.	Raw Water Hardness ppm.	Treated Water Hardness ppm.	Chemical Cost per mil.gal.	Chemical Cost per mil.gal. per 100 ppm.	Chemicals Used
Beverly Hills, Calif.	CP	6.00	250	150	$12.43	$12.43	
Santa Barbara, Calif.	CP		479	240	23.09	9.67	Gas, lime, soda ash, alum
Miami, Fla.	L-S	30.0	270	72	13.97	6.98	Lime, alum, chlorine, ammonia, fuel oil
St. Petersburg, Fla.	CP	4.50	190	98	16.48	17.90	Lime, iron
Bloomington, Ill.	CP	3.96	160	40	7.90	6.58	Lime, alum
Decatur, Ill.	CP	9.50	200	85	5.93	4.39	Lime, alum, ammonium sulfate, chlorine, calgon
LaGrange, Ill.	Z	0.75	890	85	72.07	8.94	Chlorine, salt, lime, soda ash
Ft. Wayne, Ind.	CP	14.80	308	94	15.51	5.98	Lime, soda ash, calgon, chlorine
Lebanon, Ind.	CP	0.42	396	105	20.85	7.18	Lime, calgon
Rochester, Ind.	Z	0.35	291	52	59.88	25.03	Salt, caustic soda, sodium silicate
Cedar Rapids, Iowa	CP	5.75	195	88	16.68	15.59	Lime, alum, ferrous sulfate, ferric sulfate, suspension catalyzer, chlorine, ammonia, ammonium sulfate, activated carbon, soda ash, copper sulfate, fuel oil (CO_2)
Ottumwa, Iowa	CP	4.40	284	84	37.65	18.82	Lime, soda ash, iron sulfate, oil (CO_2)
Coffeyville, Kan.	CP	2.30	175	75	16.67	16.67	Lime, alum, chlorine, natural gas, soda ash, activated carbon

* CP = chemical precipitation; L-S = lime-soda; Z = zeolite.

TABLE 2—*Continued*

Location	Type of Plant*	Amount of Water Treated *mgd.*	Raw Water Hardness *ppm.*	Treated Water Hardness *ppm.*	Chemical Cost per mil.gal.	Chemical Cost per mil.gal. per 100 ppm.	Chemicals Used
Lawrence, Kan.	CP	1.70	163	104	12.72	21.60	Lime, oil, calgon, chlorine
Topeka, Kan.	CP	6.00	340	90	12.20	4.88	Lime, calgon, alum, soda ash, chlorine, carbon
Ann Arbor, Mich.	CP	4.74	310	85	12.10	5.38	Lime, carbon, ammonia, soda ash, chlorine
Flint, Mich.	CP	20.00	288	91	12.12	6.12	Lime, soda ash, chlorine, ammonium sulfate, carbon, alum
Lansing, Mich.	CP	13.24	400	85	15.10	4.78	Lime, soda ash, coke, calgon
Minneapolis, Minn.	CP	43.4	176	78	8.32	8.48	Lime, alum, soda ash, ferrous sulfate
St. Paul, Minn.	CP	25.5	177	77	6.77	6.77	
Booneville, Mo.	CP	0.5	260	9	23.00	13.50	
Kansas City, Mo.	CP	62.0	215	110	10.57	10.35	Calgon, alum, sulfuric acid, anhydrous ammonia, ammonium sulfate, chlorine, lime, soda ash, ferrous sulfate, ferric sulfate
St. Louis, Mo.	CP	146.0	191	98	5.35	5.75	Lime, alum, iron, chlorine, ammonium sulfate, sodium silicate, activated carbon
Miles City, Mont.	CP	0.66	239	52	19.05	10.18	Lime, alum, aluminate gas
Falls City, Neb.	CP	1.0	550	200	20.00	5.70	
East Aurora, N.Y.	Z	0.372	380	36	21.20	6.20	
Elizabeth City, N.C.	CP	1.1	150	70	18.00	22.50	

TABLE 2—*Continued*

Location	Type of Plant*	Amount of Water Treated mgd.	Raw Water Hardness ppm.	Treated Water Hardness ppm.	Chemical Cost per mil.gal.	Chemical Cost per mil.gal. per 100 ppm.	Chemicals Used
Bismarck, N.D.	CP	1.3	170	75	18.00	18.50	
Columbus, Ohio	L-S	37.6	278	81	13.32	6.97	Lime, chlorine, soda ash, coke, bauxite, carbon, sulfuric acid, sodium hexa-metaphosphate, copper sulfate
Cuyahoga Falls, Ohio	Z	1.5	265	60	24.15	11.80	Salt, chlorine
Findlay, Ohio	CP	1.82	355	80	18.40	6.68	Lime, soda ash, chlorine
Lancaster, Ohio	Z	1.5	440	84	40.60	11.48	Salt, soda ash
New Philadelphia, Ohio	Z	1.5	410	76	43.00	12.90	Salt, chlorine, soda ash
Oklahoma City, Okla.	CP	18.0	260	100	12.55	7.85	Lime, soda ash, calgon, chlorine
Aliquippa, Pa.	Z	1.6	340	25	24.00	9.05	Lime, salt, chlorine
Bellevue, Pa.	Z	5.1	215	85	2.58	2.01	Salt, chlorine
Aberdeen, S.D.	CP		220	44	23.07	13.10	Pyrophosphate, ammonia, carbon, lime, alum, sodium aluminate, chlorine
Natchez, Tenn.	CP	1.2	300	76	22.00	8.92	Lime, ferric chloride
Huntsville, Tex.	Z	0.388	148	42	16.30	15.38	Salt
Elkhorn, Wis.	CP	0.25	310	80	21.00	9.13	Lime, alum
Lake, Wis.	Z	0.4	467	102	34.00	9.32	Salt
Sheboygan Falls, Wis.	Z	0.22	525	95	84.71	19.50	Salt, calgon

sion and control, interest, and accumulation of reserve funds for future needs. The estimate of operating costs must be based on clearly-defined specifications as to raw water analysis, type of treatment, etc., but it may be well to work out other estimates based on possible changes, especially expansion of the plant, so as to prepare for unforeseen contingencies.   In other

words, financial planning should carefully consider the effect on operating costs of such possibilities as a sudden increase in demand for softened water, the introduction of new industries into the area served or the possibility of an error in water analysis or estimated plant capacity.

Table 1 gives a general idea of the cost of constructing water softening plants in various sections of the country. It should be pointed out, however, that these figures are not consistent with the estimating costs used by some consulting engineers which are: $75,000 per mil.gal. for plants under 1-mgd. capacity, from $50,000 to $55,000 per mil.gal. on plants of from 3- to 4-mgd. capacity and from $25,000 per mil.gal. up on very large plants of from 5- to 50-mgd. capacity.

It should also be borne in mind that the plants at Lancaster, Ohio, Ambridge, Pa., and Cuyahoga Falls, Ohio, were built before the war and that similar plants today would cost at least one and one half times as much to construct. The general opinion of persons associated with the construction industry is that no substantial reduction in cost will occur for an extended period after the war is over.

Table 2 is a summary of the data compiled from questionnaires sent to the various plants listed requesting information on the cost of chemicals used in the softening process.

Consumer Reaction

The author recently submitted a series of questions to 125 cities where water softening plants were in operation. Replies were received from 60. In response to the question concerning the customer's reaction to the availability of a softened water supply, it is recorded that 90 per cent of the replies reported that the public reaction was favorable to a supply softened for all purposes. The question was asked whether or not it would appear advisable to provide a greater degree of softening in the supply than the community now had. The general reaction to this was that the plant was then operating to produce as soft a supply as the conditions in the community would permit. While a softer water would result in certain additional soap savings to the consumers, it would also tend to make the water more corrosive. The increase in per capita consumption of the public supply after a softening plant was installed varied from 5 to 40 per cent. In general, it was indicated that domestic water softeners which had been installed before the municipal plant started operation continued to operate but naturally required less attention than was necessary before the public supply was softened.

It is of greatest importance, once the plant is built, that a competent staff be assigned to operate it and to maintain proper records. If no qualified chemist is available in the community, one should be engaged from outside, since state health departments lack the manpower to handle the control work.

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Reduction of Chemical Odors at Nitro, West Virginia

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THE Nitro water purification plant of the West Virginia Water Service Company was built during World War I to serve the city, which manufactured explosives, with domestic and industrial water. It also furnished fire protection. The original plant was built for 40-mgd. capacity (Fig. 1). The original basins, filters, clear wells and pipe system connecting the same are still in operation today. However, since the daily output is now approximately only 3 mgd., the size of the pumps has been reduced and the filters are rotated for use periodically.

The raw water pumps have a capacity of 4,000 gpm. each and operate singly for approximately thirteen hours per day. Raw water is not pumped during the rest of the day. The raw water pump delivers water to a raw water pit and from there to the aerator pump at the influent of the 10-mil.gal. basin. The aerator pump delivers 4,000 gpm. through the aerator at 55 psi. When the basin reaches a certain elevation, the raw water pump is stopped and a check valve at the effluent of the basin opens to permit the basin water to feed back into the suction of the aerator pump which continues to operate for the full 24 hours. This permits some of the water to re-

ceive double aeration. Either or both of the basins may be bypassed and the water carried direct to the filters by using stoplogs.

Two filters are in use for about 20 hours per day until the loss of head becomes great enough to necessitate washing. Then two clean filters are placed in service after which the two dirty filters are cleaned, refilled and held in reserve. By this method all filters are maintained in operating condition.

Filtered water flows by gravity through one of two 6-ft. wood-stave pipelines from the 600,000-gal. clear well to the 5-mil.gal. clear well. The latter is maintained full or nearly so at all times.

Chemical Dosage

The chemical dosage varies as the condition of the raw water changes. However, there is no great change except for the chlorine and carbon. During the months of low flow the chlorine demand is excessive because of the nitrite content of the raw water. The threshold odor value of the raw water determines the carbon dosage. Carbon is fed continuously in varying amounts to the effluent of the 10-mil. gal. basin. Carbon is fed to the raw

KANAWHA RIVER

FIG. 1. Flow Graph—Nitro, W.Va., Water Plant

TO CITY
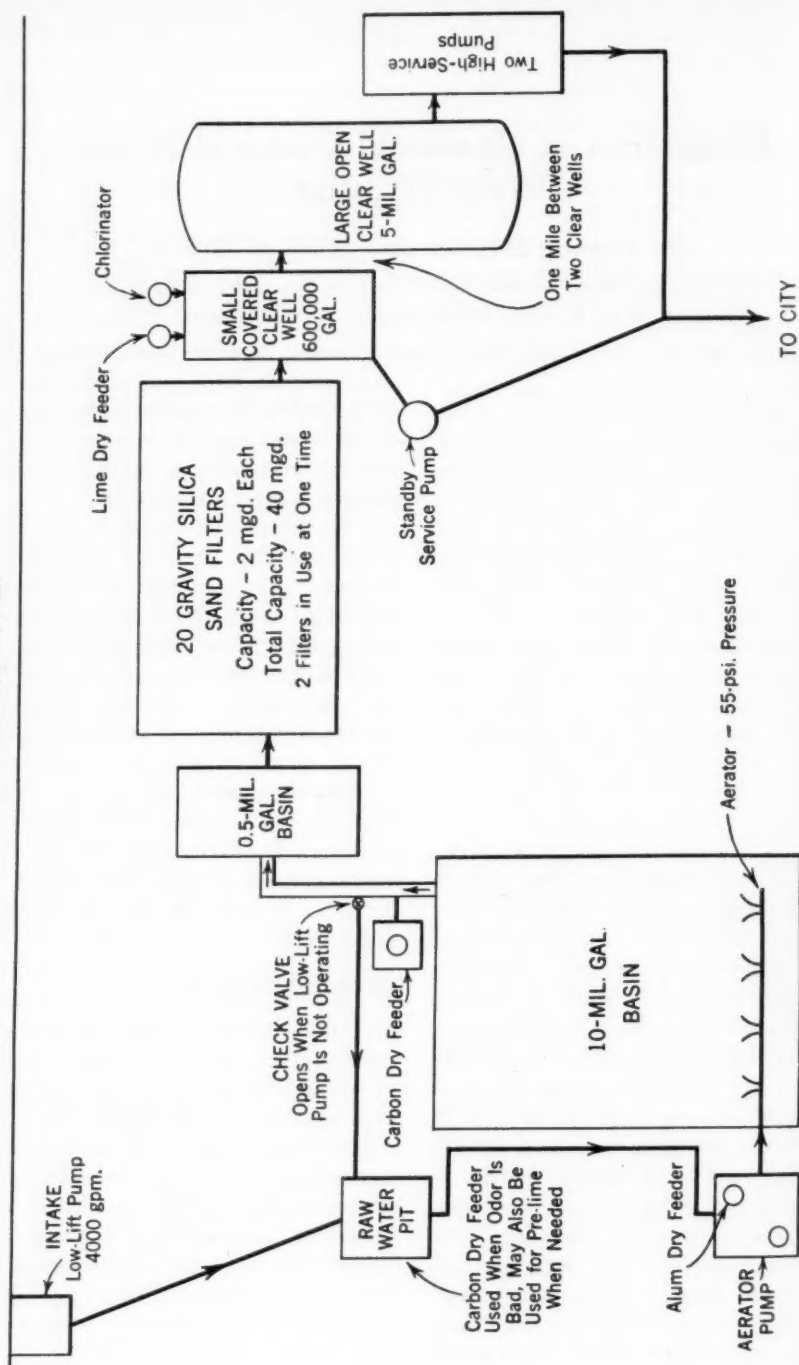
Fig. 1. Flow Graph—Nitro, W.Va., Water Plant

water before aeration when necessary. The carbon dosage to the 10-mil.gal. basin effluent is so located that, when the raw water pump is off and the water in the basin is recirculated, carbon is applied to the 10-mil.gal. basin, thereby helping to reduce the odor further and to keep down algae growths.

Chlorine is applied to the 600,000-gal. clear well in sufficient quantities to maintain a residual of 1.0 ppm. through the large clear well.

Lime is also applied to the first basin for final pH correction.

The source of supply for the Nitro plant is the Kanawha River. Upstream from Nitro are numerous large chemical plants which discharge industrial wastes into the river. As a result the Kanawha at Nitro has some chemical odor even in flood stage, while in periods of low flow the concentration of odor-producing substances in this water is almost beyond belief. A threshold odor number of 6,125 was recorded on several occasions during the summer and fall of 1944 for the Nitro supply. The lowest threshold odor found for this supply in the past two years was 19 on Jan. 4, 1945.

In November 1944 a mineral examination of Kanawha River water revealed:

	ppm.		ppm.
Chloride	52	Free Carbon	
Nitrate	4.4	Dioxide	10
Sulfate	33.6	Iron	0.14
Calcium	32.5	Manganese	Trace
Magnesium	4.7	Hardness,	
Sodium	19.6	as $CaCO_3$	101
Alkalinity—		pH	6.7
M.O., as $CaCO_3$	33		

Monthly average threshold odor numbers on Kanawha River water at Nitro for the year beginning May 1944 were:

1944		1944	
May	188	November	1,435
June	743	December	124
July	1,539	1945	
August	942	January	42
September	4,300	February	78
October	2,179	March	317
		April	1,055

Water from Coal River, which empties into the Kanawha River at St. Albans, furnishes water to the St. Albans purification plant of the West Virginia Water Service Company. Coal River water is of excellent quality, so that during the winter and spring months there is no trouble with odors at that plant. In the summer and autumn months of low flow, however, the Kanawha River water backs upstream into the Coal River, creating odor problems as bad as, and sometimes worse than, those in Nitro. The highest threshold odor number ever determined at the Charleston laboratory of the West Virginia Water Service Company was 8,333. This was on a river sample from St. Albans collected on Sept. 7, 1944.

Continued operation of the two plants using this supply made it necessary to devise a method of either removing or greatly reducing this odor. This work was started in 1935 when odor was first encountered in any serious measure.

Odor Control

A plan of treatment using aeration and activated carbon operated with considerable success until the summer of 1943. Until that time the odor could best be described as "sweet-chemical." The opening of a synthetic rubber plant and a butadiene plant above the

intakes at Nitro and St. Albans, along with increased industrial wastes from other chemical industries rushed with war work, has made this problem acute in the past two years. At the same time the odor changed to an unpleasant one, smelling like varnish at times and at other times like mustard.

Three methods of odor reduction have been investigated, some results of which are reported below.

Break-Point Chlorination

A series of laboratory experiments and one plant-scale test have been conducted to determine the efficiency of break-point chlorination as a means of odor reduction in Kanawha River water. Ammonia nitrogen concentration is 4 ppm. or more in the summer and autumn months. Break-point chlorine demand ranges from 3.5 ppm. in the winter to 46 ppm. or more in dry months.

Aerated raw water was used for the laboratory break-point and combined odor tests. One-half of the sample was retained as a control and the other half chlorinated about 1.5 ppm. above break-point. Both portions were then allowed to stand for a contact period which varied with different samples from two to 22 hours. After the contact periods, threshold odors were determined on both portions. The chlorinated portion was not de-chlorinated. In all cases the threshold odor numbers of the two portions of any particular sample were the same or very nearly so.

Break-point chlorination on a plant scale was tried at Nitro from Apr. 28 to May 2, 1944. Chlorine was added to the filtered rather than to the raw water for several reasons: (1) This required no change in chlorinating equipment, as chlorine is normally fed at this point. (2) Because this water had to pass through the 5-mil.gal. clear well, ample contact time was assured. (3) By chlorinating the raw supply it might have taken over a week to get a free chlorine residual through the 10-mil.gal. basin.

Chlorine was added to the small clear well at the rate of from 8 to 10 ppm. during the hours of filtration on these days. By May 2 a free chlorine residual of 1.3 ppm. was found in the plant effluent. Throughout the test the odor number of the filtered water, before chlorination, was 12. On May 1 the odor number of the plant effluent was 5, while on May 2, the first day to show free chlorine, it was 12. Since no odor reduction was found from this test or in the laboratory experiments, it was concluded that break-point chlorination reduces this type of odor very little or not at all.

Activated Carbon

From plant experience and laboratory tests it has been found that beyond a certain point the addition of more activated carbon removes little odor and certainly is not economical. At one time, before the introduction of double aeration, the rate of feed of carbon at the St. Albans plant was over 340 ppm., and this did not solve the odor problem by any means. For the rest of the period preceding double aeration, 170 ppm. was not an uncommon dose.

In one laboratory test aerated raw water from the St. Albans aerator was treated with varying amounts of Aqua Nuchar up to 855 ppm. A little alum was added and a contact period allowed equal to that in the basins at St. Albans. Results were as follows:

Activated Carbon lb./mil.gal.	Threshold Odor Number After Treatment
0	420
1,430	124
2,145	62
2,860	41
3,575	15
7,150	6

Filtration of the finished water through granular activated carbon filters has received attention. Two 1-gal. jugs were arranged as upflow filters and set to run 24 hours per day, using Nitro finished water. Jug No. 1 contained 1 lb. 1 oz. of granular Nuchar carbon; No. 2 contained 2 lb. 14 oz. of Darco granular carbon. The results in the tabulation below were secured before the jugs became clogged beyond repair and it became impossible to operate the filters any longer. The flow was controlled so that it would about equal a flow of 0.6 gpm. if this same amount of carbon were placed in an ordinary filter to a depth of 18 in.

Date	Nitro Service Pump Threshold Odor No.	Effluent Jug No. 1 Threshold Odor No.	Effluent Jug No. 2 Threshold Odor No.
Oct. 10, 1944	25	0	0
Oct. 17, 1944	60	0	0
Oct. 25, 1944	21	0	0
Oct. 31, 1944	13	0	0
Nov. 10, 1944	70	0	4
Nov. 15, 1944	80	0	5
Nov. 21, 1944	60	4	6
Nov. 28, 1944	19	0	2
Jan. 10, 1945	4	0	0
Jan. 17, 1945	4	2	0
Jan. 25, 1945	8	0	0
Feb. 7, 1945	50	11	—
Feb. 15, 1945	60	8	—
Feb. 20, 1945	9	5	—
Mar. 6, 1945	3	2	—
Mar. 14, 1945	4	2	—
Mar. 21, 1945	40	10	—
Mar. 27, 1945	25	10	—
Apr. 5, 1945	8	4	—

The conclusion is that granular activated carbon is valuable in reducing the last fraction of odor after the bulk has been reduced by aeration.

Aeration

Aeration by high pressure has been found to be by far the best means of reducing the chemical odors encountered in Kanawha River water. As much as 98 per cent of the odor has been removed by a single aeration at 110 psi. at the nozzle of the aerator.

The aerator at Nitro was designed by and constructed under the supervision of J. R. Peck, the engineer in charge of the Nitro plant. It consists of 30 No. 11-BA 2-in. Spraco nozzles arranged along a pipe which decreases in diameter in calculated steps from 18 to 8 in., so that practically the same pressure is found at all nozzles. The pumping expense for a single aeration at 55 psi., according to Mr. Peck, is less than the cost of applying 17 ppm. of activated carbon.

When odor is present in the supply at St. Albans, the water is aerated twice. The first aeration is of the raw water through five 2-in. Spraco nozzles with about 30 psi. pressure from the intake pump. Because of lack of space this aerator has four sides boarded up. There is no evidence that this has led to any serious decline in its efficiency.

A second aerator, constructed at St. Albans late in the summer of 1943, picks up the treated water at the end of the first basin and aerates it at about 30 psi. This water then flows into the second basin. Three sides of this aerator are boarded up.

Efficiency of High-Pressure Aeration

Experiments to determine the most efficient method of operation for high-
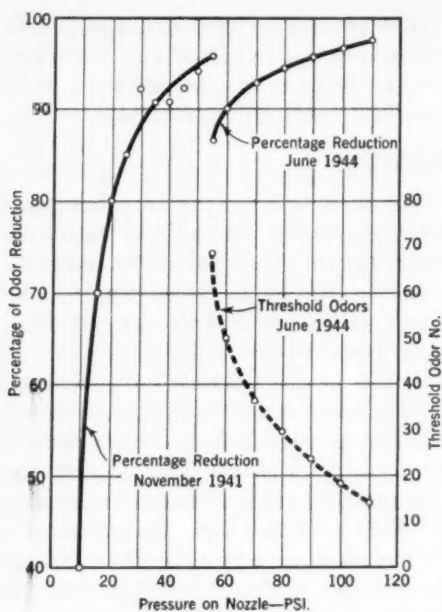
FIG. 2. Threshold Odor Reduction by Aeration Using 2-in. Spraco Nozzle on Kanawha River Water. Raw Water Thresholds: 1941—1,660; 1944—500

pressure aeration have been conducted in the past four years. In the fall of 1941 an experimental aerator, using a single 2-in. Spraco nozzle, was built at Nitro. Odor tests were run on the raw water and on samples from the aerator using pressures of from 10 to 55 psi. in 5-lb. steps. The threshold odor number of the raw water was 1,660, 95 per cent of which was removed at the highest pressure. This sample had a threshold odor number of 75 (Fig. 2). Treatment of this sample with activated carbon resulted as follows:

The threshold odor was reduced from 75 to 10 by 34 ppm., to a threshold of 5 by 68 ppm., to 4 by 103 ppm., and to 2.5 by 137 ppm.

The present aerator at Nitro was built as the result of this experimental work and its use, together with car-

bon, served to eliminate most of the odor until the summer of 1943.

Under present odor conditions of the river, substantial amounts of odor are removed by raising the pressure on the aerating nozzle from 55 to 110 psi., which is the highest pressure so far tested. This was demonstrated in May 1944 when, on a special one-nozzle aerator, odors were determined. on samples of from 55 to 110 psi. The raw river water had a threshold of 356 which in the 55-psi. sample was reduced to 31. The odor dropped consistently with an increase in pressure until the 110-psi. sample had a threshold of 7, or 98 per cent removal.

About the same results were secured when this test was repeated in June. The river odor of 500 dropped to 14 in the 110-psi. sample (Fig. 2).
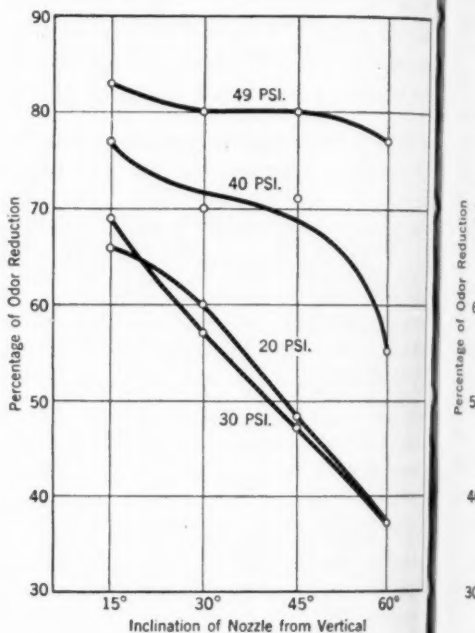
FIG. 3. Threshold Odor Reduction by Aeration on Kanawha River Water. Threshold Odor 833—17 ppm. Alum Added to Raw Water Before Aeration at 49-psi. Pressure

Trial runs were made at the Nitro aerator in September 1943 to determine if any position of the nozzles, other than vertical, would give better odor reduction. Kanawha River raw water, to which 17 ppm. of alum had been added, was used. Nozzles were slanted off the vertical at 15, 30, 45 and 60 deg. Samples were taken at 49, 40, 30, and 20 psi. pressure. Best reduction in the odor was secured at 15 deg. and at 49 psi. This reduction was 83 per cent, but at the same pressure and at 60 deg. it had dropped to 77 per cent. In general the more nearly vertical the nozzle, the better was the efficiency. Figure 3 shows these results.

A second aeration of once-aerated and settled water from the 10-mil.gal. primary basin at Nitro was also the

FIG. 5. Threshold Odor and Residual Chlorine Reduction by Aeration of Plant Effluent From Second Clear Well Using 2-in. Spraco Nozzle

basis of a series of odor determinations (Fig. 4). The threshold odor of the once-treated water was 313. What the odor of the raw water was before treatment was impossible to determine because the water in the basin was a mixture of several days' pumping, and what percentage of one or the other day's flow was present could not be calculated. Odor tests on the raw water at that time, however, indicated an odor number between 800 and 1,000.

Aeration of this once-aerated water reduced the odor less, on a percentage basis, than it did in the case of raw water. The fraction of odor remaining appeared to be of a type more difficult to remove. Best results were obtained at 49 psi. and at an inclination of 15 deg. This sample showed a reduction of 73 per cent. Estimating the original odor of the raw water at 833, the total

FIG. 4. Threshold Odor Reduction by Second Aeration of Once-Aerated and Settled Water From Primary Basin Effluent—Threshold Odor 313

reduction by double aeration plus 34 ppm. of activated carbon being fed to the basin at that time (see Fig. 1) was 90 per cent. Compare this reduction with that secured in 1941 when a single aeration at 50 psi. removed 94 per cent.

As the odor is reduced step by step, it becomes increasingly difficult to effect a reduction in the next step. Aeration of the plant effluent, using the water from the large second clear well, was tried in April 1944. With a threshold of 11 and the characteristic sweet chemical odor, this was reduced to a threshold odor of 9 at 10 psi., 7 at 20 psi., and 5 at 25 psi. (Fig. 5).

Aeration of water from the second clear well was tried again when the odor was only 2 (Fig. 5). In this case there was almost no odor reduction even at 60 psi., which sample had an odor number of 1.8. Incidental to this investigation was the finding that aeration does not greatly reduce the residual chlorine in water. Before aeration this water showed 0.8 ppm. residual chlorine when tested by orthotolidine with a five-minute contact period. After aeration in steps of 10 psi. to 60 psi. all samples, except one, had a residual chlorine of 0.5 ppm.

A problem encountered in high-pressure aeration is the abrasion of the diffusion vanes, or turbine center, of the nozzle. Abrasion is worse when the river has considerable turbidity. A few tests were run to see if these centers could be inverted or eliminated. With the turbine center inverted to give a high spray, a sample at 53 psi.

had a threshold odor of 70. When the turbine center was in the normal position and at 55 psi., and other conditions were the same as above, the odor number was 68. Other results showed that little or no change occurs when the turbine center is reversed. At about 90 psi. the same reduction was observed with the turbine center removed as with it in. It is impossible to draw any general conclusions from these few tests, which were not repeated.

Because of the efficiency of high-pressure aeration in removing high percentages of these chemical odors, it must not be assumed that the same results can be obtained with odors of other types. In the second week of September 1944 a musty odor was observed in the raw water at Nitro. In spite of aeration at 55 psi. and the addition of 34 ppm. of carbon, it was not entirely eliminated and could be detected in the finished water.

On very cold days the Nitro aerator cannot be used because of the ice which builds up around it. Fortunately there are few days cold enough to cause trouble at Nitro and the river water is usually not so odorous during freezing weather.

Threshold Odors

All threshold odor numbers reported here were determined at room temperature. Checks on the same samples at room temperature and at 60°C. have shown that the latter odor numbers are usually considerably higher.

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Re-employment of Servicemen

An article based on a pamphlet distributed to its member companies by the American Water Works & Electric Co., New York, N.Y.

In order to provide a workable procedure regarding the re-employment of veterans of the armed forces, the suggestions which follow have been prepared by the American Water Works & Electric Company, New York, for the guidance of its personnel section. Although this article substantially follows the American Water Works & Electric Company's text, it has been adapted to apply to any public or private water utility facing similar problems.

Company Policy

It should be the intent of any company to live up to the spirit as well as the letter of the re-employment provisions of the Selective Service Act. A company should want its servicemen and women to resume their jobs if they wish to do so, and it should want to do everything in its power to help returnees to make a satisfactory transition from military to civilian life (which some will find difficult), and, if they have acquired new skills during their years of service that qualify them for more responsible jobs, to place them in such jobs, if and when conditions within the company make it possible.

Provisions of Selective Service Act

The individuals involved are those who (1) hold certificates of satisfactory service, (2) held permanent positions with the company before service, (3) are still qualified to perform the duties of such positions, and (4) apply for re-employment within 90 days of completion of service. Such persons (5) must be reinstated to a position of like seniority, status and pay, (6) shall be entitled to participate in insurance and other benefits in accordance with established rules, and (7) shall not be discharged for other than cause for a period of one year.

Suggested Steps

Once the veteran has indicated within the prescribed 90 days—although a company should not necessarily hold rigidly to this 90-day rule—his intention to return to his former employment, it is desirable to effect his reinstatement as promptly as possible. The first aim should be to make the returning veteran feel that he is welcome, without singling him out as an object of curiosity. The whole attitude should be such that he will feel he belongs to the group of employees and is one of them, rather than a conspicuous stranger.

The responsibility for welcoming the former employee and for his re-employment should rest, of course, with the company or department manager. The company should rely on the tact and judgment of its officers in conducting such interviews, rather than suggesting any prescribed formula.

However, prior to the time of such interview, a manager or superintendent

should make a thorough analysis of the personnel situation in his company so that the effect of reinstating the veteran in the appropriate job will be clear in his mind, and he will know precisely what may be offered. As a guide to fixing this picture in the manager's mind, the following comments are offered:

1. *How to Determine Job To Be Offered Returning Veteran*

Study the Problem Now: Generally speaking, if a company's job structure is stable, there will be no problem in determining what job should be offered. If, for example, the employee was an operator at the time of his induction, he should be reinstated as an operator. If the veteran, during his service with the armed forces, has acquired additional skills which might qualify him for some higher rated position in the company, his advancement thereto should be discussed by the staff members concerned, but in the meantime he should be promptly reinstated in employment as previously indicated.

2. *How to Determine the Rate of Pay*

Pay the Full Rate for the Job: Upon being reinstated in his former position or one of like seniority and status, the veteran should be paid the rate currently attached to such job, not the rate he was being paid at the time of induction. In the event the job classification in which the employee falls has a rate range, it will be necessary to determine at what level in such range this particular employee should be paid. This may be done by adding to his rate at the time of induction any general increases which have been granted. For example, let us assume that John Jones was inducted into the armed forces in November 1942, at which time he was

receiving 60¢ per hour as an operator and at which time the rate range for an operator was 55¢ to 75¢ per hour. On June 1, 1945, John Jones, having received an honorable discharge, applied for reinstatement in his former job. Subsequent to his induction a new rate range of 65¢ to 85¢ per hour for the position was approved by the War Labor Board, and during the period of his military service the two operators currently on the payroll were granted merit increases of 3¢ each on two occasions. In the first place the general level of pay for the position of operator has been increased 10¢ an hour; in the second place other operators have received increases aggregating 6¢ an hour. Therefore, the minimum rate for John would be 65¢ per hour. Yet this rate does not seem altogether fair, as his two fellow operators are earning 71¢ per hour. It would seem, then, that John should be started at 71¢ per hour, his honorable discharge constituting the basis for an additional 6¢ per hour.

In the case of a job with a single rate, no problem exists, of course.

3. *Displacement of Present Employees*

Follow the Line of Seniority: If there is a vacancy in the job classification formerly occupied by the returning veteran, his reinstatement entails no complication. The man simply re-enters his job at the appropriate rate of pay without any disturbance of other employees or jobs. If there is no vacancy, however, in the job classification to which the employee properly must be assigned, it may be necessary to demote or lay off some other employee. Workers hired to fill vacancies created by the induction of men into the armed forces are generally on a temporary basis. Unfortunately

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HONORABLE DISCHARGE EMBLEM

Any Returning Employee Who Holds Honorable Discharge Papers Will Be Entitled to Wear This Button—His Fellow Employees Should Be Able to Recognize It Immediately As a Symbol of Honorable Service to the Country

however, the identity of the job in which the replacement has actually occurred may have been obscured by subsequent turnover and where there is a full complement of employees necessitating the release of one person to make room for the returning veteran, the situation should be thoroughly analyzed in writing and discussed by those concerned with personnel. This should be done well in advance of the time when the veteran presents himself for reinstatement. An immediate study should be made of how work is to be reassigned when the occasion demands. The best rule to follow, it is felt, is over-all company seniority, giving due regard to the ability of the serviceman to perform the work.

Veteran Has Super-seniority: It should be emphasized once more that pending clarification of the Selective Service regulations, a company should abide by the present interpretation that the returning veteran is entitled to reinstatement in his old job or one of like seniority and status, even though

an employee of greater service must be displaced (1).

4. *Job Requirements*

Veteran Must Receive Fair Break: Such matters as night shift assignments, less popular vacation periods and disagreeable duties should not be pushed off on the returning serviceman because he has been away a couple of years. His supervisor and his fellow employees should accord him complete equality in the matter of job requirements. He should have at all times equal treatment with his fellow employees. In thinking about this it would be well to adopt the attitude of mind that the returned serviceman has never been away.

5. *Veteran's Legal Rights and Privileges*

Be Generally Familiar With Federal Veterans' Benefits: It would be helpful to anyone coming in contact with veterans to familiarize himself with the information contained in the booklet, "The Problem of Re-employing Servicemen: How to Handle It" (2). An interviewer should be especially familiar with the rights and privileges provided for the serviceman, and be in a position to refer him to the local authorities whose duty it is to advise and help veterans. It is not recommended that an individual attempt to advise the veteran himself, but a genuine interest in his problems should be shown and he should be made to feel the individual's desire to help him.

6. *Physical Examinations*

Follow the Rule of Reason: A returning veteran should take a physical examination if such is required for employment in the company although, generally speaking, physical handicaps

which will not preclude the veteran from performing any job for which he is otherwise qualified should not result in a refusal to reinstate him. It should be a company's aim to utilize the services of every veteran who was formerly employed, unless he has suffered disabilities which beyond any doubt in a medical examiner's opinion would prevent him from carrying out the functions of any position which the company has to offer. In such circumstances one should be very sure that by rearranging jobs it would, in fact, be impossible to re-employ the disabled veteran.

Where an obvious physical handicap exists or where a manager feels after his interview with the veteran that there is mental or nervous instability, the reinstatement of the former employee and his assignment to an appropriate job should be immediately discussed with those concerned with personnel problems and a solution sought.*

7. Forms

These Are Necessary: The returning veteran should not be expected or required to complete an application for employment. However, all other forms which must be prepared at the time a new employee is put on the payroll should usually be filled out. There will probably be company forms needed for

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* In the original document, questions of this nature were directed to be referred to the home office of the American Water Works & Electric Company. In the case of a water utility, the management of which is coextensive with the area served, the manager or superintendent would doubtless consult a local physician or psychiatrist. If there is no psychiatrist in the locality, it may be found that there is a psychologist associated with the public school system who might be glad to make his services available.

the record, and of course the withholding exemption certificates for federal income tax purposes should be executed by the employee.

8. Reinstatement of Employee Benefits

The Veteran Will Need This Protection: Any group life insurance coverage, health, accident, unemployment or other benefits should be re-established as of the first day at work. Such coverage should be based on the current rate of pay and on the employee's length of service up to the date of reinstatement, counting all time elapsed while he was in military or naval service.

9. Follow-up

Give the Veteran Interest and Encouragement: This is an important part of the program and should be done methodically, although informally. It probably can be done largely through the supervisor. There is no way of anticipating how difficult or easy will be the transition period for the serviceman. It is very likely, however, that in some cases difficulty will be encountered. No civilian can really appreciate the differences between civilian and military life, or the impact that actual combat experience will make on the individual. Therefore, considerable patience and tact may be required in handling some cases.

In any event, the purpose of any program should be to help the veteran make the least painful and speediest possible adjustment to civilian life and to encourage the feeling of self-respect that comes from making a useful contribution to society. Allowances must be made for a certain confusion and indecision he may feel at first and every effort made to help him where help seems indicated. It is generally agreed

that much responsibility rests upon the employer for the discharged veteran's successful readjustment to civilian living. A follow-up record should be kept on each reinstated employee until it is evident that he has made a satisfactory adjustment.

The Handicapped Veteran

The handicapped veterans fall into two main categories: those with physical disabilities and those with psychoneurotic disturbances.

1. *Physical Disabilities*

Under the heading, "Physical Examination," are suggestions regarding the reinstatement of veterans in this category. It should be added that disabled veterans are eligible for extensive government rehabilitation and retraining which should be considered when attempting to find a suitable job for a handicapped veteran.

It would be well, while making an analysis of a personnel situation, to give consideration to the kinds of jobs that could be performed by partially incapacitated veterans.

2. *Psychoneurotic Disturbances*

This type of disability needs careful study and constant but unobtrusive follow-up. Also, special care should be taken to give these men employment they are able to perform successfully. The most familiar symptoms of these cases are (1) the tendency to worry unduly and (2) an anti-social attitude. Anxiety may be caused by finances, family affairs and worry about job performance. Kindly counsel and constant interest, plus considerable tact and patience, may be required in handling these cases; and interest and good intention must not be allowed to taper off.

The man with anti-social tendencies may present the hardest problem of all because of the eventual effect his attitude may have on other employees. It will probably be necessary to make a special effort to enlist the co-operation of his fellow workers in dealing with cases of this kind. Any problems of this nature that seem particularly difficult to cope with should be given special study, perhaps in consultation with a psychologist or physician.

Temporary Employees

Strictly interpreted, the law deals only with permanent employees on military leave, and neither the temporary employee, nor one who replaced a permanent employee and later was himself drafted, has reinstatement rights under the law. Generally speaking, however, a company should take care of the temporary employee who joined the armed forces in the same manner as the permanent employee, insofar as it is able.

Veterans Not Previously Employed by the Company

In every community there will be numbers of returned veterans who, for various reasons, such as age at time of induction, will not have jobs to which to return. In many cases these younger men will want to take advantage of the opportunities they are offered to continue their education, and they should be encouraged to do so. But there will be some who will prefer to work. It is felt that each community should make every effort to help these young men. Therefore, if conditions permit, employment needs above and beyond those to be filled by a company's permanent and temporary returned veterans should be filled from this group. Local veterans' service organizations will prob-

ably be able to provide applicants for such positions. It is good for water works executives to be familiar with these activities in the community and to some extent to identify themselves therewith.

Summary of Veterans' Reinstatement Program

1. Be familiar with provisions of the Selective Service Act re re-employment of returned veterans.

2. Prepare a complete company and military service record for each permanent and temporary employee on military leave.

3. Make an analysis of probable postwar personnel needs.

4. Discuss plans and procedure with supervisory staff.

5. Work out a definite procedure for reinstatement in advance. Have necessary personnel forms ready.

6. Plan a definite follow-up procedure in which supervisors are to participate.

7. Be familiar with local veterans' assistance agencies.

8. If any problem is presented by the physical or mental condition of the veteran, the advice and help of a physician or psychologist should be sought —though this depends on the individual problem. Medical or psychiatric advice should probably *not* be sought in the presence of the veteran.

Suggestions From a Veteran

Considerable help may be found in the following ideas, taken from a statement made by a returned veteran of maturity and judgment:

1. Tell the veteran that you are glad that he is back.

2. Help him to feel that his services are really needed.

3. Make it a point to show him some attention such as to ask his opinion on something (always a compliment) if there is any justification for doing so.

4. Tell him that you appreciate the difficulty of the return to civilian life and invite him to discuss his problems. Remember that he will miss the activity and excitement, the unique comradeship of others in uniform, the out-of-door life (in many instances). Also he will have more responsibilities and obligations in civilian life. There will not be so many to take care of the details of living, or at least to do the thinking and planning for him. In its way, life in the armed services is relatively carefree or at least restricted to a few specific and well-defined duties. It is little wonder that sometimes the veteran is restless and nostalgic.

5. Don't ask him too many questions and respect his wishes if he dosen't want to talk. There are a number of reasons why servicemen don't like to describe their personal experiences:

(a) Modesty and, equally important, the fear of being thought a braggart and a bore;

(b) Disappointment in the part he has had to play; that is, embarrassment over the fact that his record is not more distinguished or glamorous.

6. If he has been wounded it is even more important not to ask personal questions.

7. Don't sympathize with a wounded man or make him feel that you consider him an object of pity.

8. Don't offer to help a wounded man unless he invites it in some way. I heard one man, who had lost his leg, upon being asked if he'd like to have his wheel chair pushed up an incline

reply: "Hell, no, I'm no cripple." Actually his feelings were hurt.

9. Don't complain that all of the cigarettes, meat and butter go to those in service. After all some of them are risking their lives and supporting families on pay that often is lower than the pay in industries engaged in war work.

10. Above all treat the veteran as the person he actually is; the same fellow human being that he was before he went away on a leave of absence.

Soldier to Civilian: Problems in Readjustment, written by a psychiatrist who has had military experience, offers helpful advice to personnel managers and others dealing with returning servicemen (3).

References

1. Selective Service Bulletin 190A. Government Printing Office, Washington, D.C. (10¢ per copy.)
2. *The Problem of Re-employing Servicemen: How To Handle It*—An Explanation of the Selective Service Act and the G.I. Bill of Rights. Prentice-Hall, Inc., New York (1945). (Pamphlet, 32 pp. $1.00 per single copy, 30¢ per copy in lots of 100.)
3. PRATT, GEORGE K. *Soldier to Civilian: Problems in Readjustment.* Whittlesey House, New York (1944).

ADDENDUM

Since the above story was set in type, information has reached Association headquarters concerning the policies followed by the Johns-Manville Corp.

The first principle of the plan is individual treatment for each former employee returning from service. The company stresses that it attempts to "obey the spirit as well as the letter of the laws" devised for the protection of veterans.

As an introductory step to re-establishing relationships with former employees who were in service, the company maintained contact with them through a bi-monthly house organ, letters from the co-workers left behind and gift packages at Christmas, with the intention of making the servicemen feel that they were merely "on leave of absence." The company also wrote to each man, over its president's signature, asking about his postwar plans, what new skills he might have acquired and his intentions regarding re-employment at the company.

The company has trained 40 men to function as "veterans' advisers" and many of its larger offices have advisory committees to work with the advisers. In addition, its key executives are kept abreast of all intramural veterans' affairs. The company has prepared a loose-leaf manual for the guidance of all those concerned in the program, setting forth the company policy and including copies of government and company forms of concern to veterans, instructions on interviewing veterans and outlines of the laws protecting veterans and of the government and company benefits to which returning veterans are entitled.

The company has been making job inventories so as to know how the veterans could be fitted in when they returned, and what positions are or could be opened to disabled men.

Through the medium of the house organ, the veteran has been kept informed regarding the procedure to be followed for reinstatement. He has been kept up-to-date on personnel and he knows to whom to go for an inter-

view, whether to his former boss or the "veteran adviser," and after a hearty welcome from one of them he moves on to the personnel manager for the routine filling of record forms, a medical examination and reassignment to his former job or to another one of equal or greater responsibility.

The company tries to do what it can for the returning serviceman who had been only a temporary employee, often a replacement of a draftee. If no job can be found for him, an effort is made, through local community services, to arrange for his employment elsewhere.

The company attempts to arrange for or extend the leave-of-absence for a serviceman who wishes to avail himself of the educational opportunities provided by the "G.I. Bill of Rights."

A follow-up system is designed to ascertain that the veteran is resituated suitably and that no newly-acquired skill is overlooked.

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Centrifugal Pump Peculiarities

By Robert W. Angus

Cons. Engr. and Prof. Emeritus of Mech. Eng., Univ. of Toronto, Toronto, Ont.

Presented on Mar. 20, 1945, at the Canadian Section Meeting, Toronto, Ont.

PRACTICALLY all pumping units now being installed in water works plants are composed of centrifugal pumps driven by electric motors, steam turbines or internal combustion engines, and few plants today use reciprocating pumps. Experience with centrifugal pumps has now been sufficiently extensive for operators to know many of their peculiarities; yet there are features connected with their use that are worthy of review.

Setting of Pump

The setting of the pump is perhaps one of the most important matters, as it may easily account for any later defective operation. It is, of course, well known that the pump should be set as little above the well level as possible, and it is usually preferable to have it below this level, except for the difficulty of unwatering it, if for no better reason than ease of priming and freedom from the foot valves on the suction line. That the pump is unduly sensitive to suction conditions is a matter of general experience, and long and crooked suction piping is to be avoided.

The author has made tests on the effect of foot valves, which showed that resistance in these might cause a high vacuum at the suction flange of the pump and a corresponding decrease in discharge [Jour. A.W.W.A., **37** : 70 (1945)]. High-suction vacuum naturally induces air leakage into the pump through the glands, and also releases whatever air there is in the water being pumped. In order to investigate the effect of air leakage, a number of experiments were run on a 4-in. pump, in which various volumes of air were admitted into the suction pipe after carefully sealing the glands so that leakage was practically stopped there.

In this pump the percentage decrease in discharge at a given head was roughly proportional to the percentage, by volume, of air admitted, so long as the latter remained below about 1.5 per cent (see Fig. 1), but thereafter the water discharge fell off very rapidly until there was a decreased discharge of over 40 per cent when 4 per cent of air, by volume, was admitted. This merely confirms the well-known fact that at low suction lifts, and consequently low air inlet leakage, the exact elevation of the pump is not so important. There is a critical elevation for each pump and condition, however, and if this is exceeded the loss of water increases at a rapid rate. Clearly the height of the pump above the well level should be kept substantially below this critical elevation.

Specific Speed

Fortunately the importance of this matter is now recognized by the pump builders, and they have found that for each head, discharge and speed there

is a maximum height above the well at which each pump should be set. These three quantities are combined in a formula for "specific speed" which is defined by:

$$\text{Specific speed} = N \times \sqrt{G}/H^{0.75}$$

where N is the revolutions per minute, G is the discharge in U.S. gallons per minute and H is the head in feet.

Pump builders have co-operated in connecting the specific speed and head with the maximum allowable suction lift, basing their conclusions on laboratory tests and on experience with pumps which they have installed. Through the Hydraulic Institute they have given these maximum elevations in the form of diagrams, separate ones being used for single-entry pumps, for double-suction single-stage pumps, etc.

As an illustration, there are four double-suction single-stage raw water pumps at the Victoria Park pumping station, Toronto, Ont., rated at 24, 30, 48 and 60 mgd., respectively, all of them for 9-ft. suction lift and for a total head of 82 ft. The two larger pumps operate at 750 rpm., and if this speed had been adopted for all four pumps, their specific speeds and maximum suction lifts, including velocity head and friction in the suction pipe, would have been, according to the chart of the Hydraulic Institute:

Size of pump, mgd. (U.S.)..	24	30	48	60
Specific speed at 750 rpm...	3545	3970	5010	5610
Maximum allowable suction lift, *ft.*	18	15	5	—
Necessary suction pressure, *ft.*	—	—	—	5
Specific speed at 500 rpm...	—	—	3340	3749
Maximum allowable suction lift, *ft.*	—	—	20	17

Since the velocity heads in the two larger pumps are 2.3 and 2.1 ft., respectively, and since friction must be allowed for, it is clear that, while there is a margin on the two smaller pumps when run at 750 rpm., the two largest
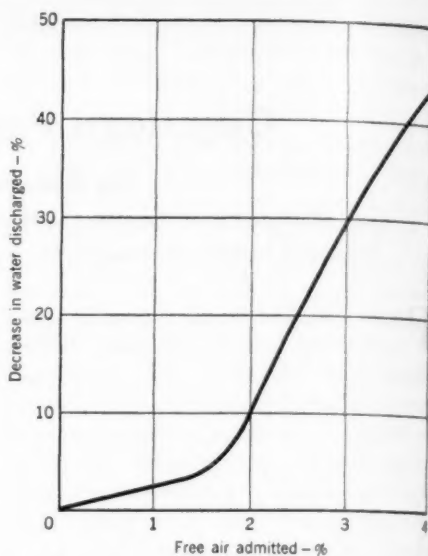
FIG. 1. Decrease in Discharge of Centrifugal Pump Due to Admission of Air Into Suction Pipe

pumps could not be run at this speed and had to be changed to 500 rpm., which is the next available speed.

Setting pumps too high not only causes them to lose capacity, but also means noisy operation and cavitation, which is frequently destructive. As the capacity of a pump at fixed speed is gradually increased by lowering the discharge pressure, a point is finally reached where the characteristic curve is nearly vertical, which point naturally corresponds to the limiting output of the pump. Cavitation and noise are present at such discharge and in its vicinity, and the higher the suction lift the lower this limiting output is. It is to avoid too close an approach to this point that the charts referred to above have been made. Noise in a pump operating near this limiting point may often be stopped by the admission of a very small volume of air to the suction pipe.

Power Failures

Power failures on motor-driven centrifugal pumps present some problems. A check valve is usually placed on the line close to the pump, and if this acts slowly there is backward flow through the pump which reverses its direction of rotation unless specially prevented. If the check valve does act rapidly, however, water-hammer pressures are often excessive, resulting in damage to the plant. A number of cases of the latter have recently come to the author's attention.

Water hammer, contrary to a common belief, is often dangerous in low-head pumping. The author made some tests on a 12-in. pump working against a 55-ft. static head, with a discharge line only about 350 ft. long, and recorded the pressures with a Crosby indicator with a 30-lb. spring. When the switch was opened the pressure drove the indicator pencil off the top of the drum, indicating a pressure of more than 60 psi., and the first pressure wave measurable showed 50 psi. or a 115-ft. rise. As stated, this was a short line and the pipe velocity was under 4 fps. However, in another case where the static head was 40 ft. and the line was over 2,000 ft. long, the pressure rose to 83 ft. with normal pipe velocity of slightly over 7 fps. In both cases the pressure rise was high enough to cause some anxiety, which was further aggravated in the first case by the noise and shock plainly observed at the pump, while in the second case there was no apparent shock on the system. In the first case, the maximum pressure rise occurred 2.6 seconds after cutting off the power, whereas it took 13.0 seconds in the latter case.

Short lines are sometimes more dangerous than long ones, because in the latter the water takes an appreciable time to slow down before coming backward, thereby giving the check valve time to close gradually and prevent any real reverse flow of the column. In the pipes the water column reverses in much less time, as the above measurements show, and actually before the check valve has had time to close. The water then gains a high backward velocity, suddenly closing the check valve and producing high pressures. The maximum pressure rise, in feet, reaches about one hundred times the velocity of the water in the pipe at the time the valve suddenly closes.

Sometimes an effort is made to decrease the danger by using an air chamber, but this is far from the best method and does little good unless the chamber is placed on the line near the pump and has a large short connection with the pipe. Air chambers connected to the line with a fairly long branch pipe are of little value and, of course, any virtue the device has will be lost unless there is a good volume of air in the chamber under normal conditions. A well-designed check valve, with a proper controlling mechanism which permits the greater part of the closure to be rapid and the latter part gradual, offers a good solution, and a number of such valves are now on the market. It is a fact that, unless the pump is equipped with a heavy fly-wheel, as is sometimes the case, the pump will often run backward before the check valve closes, but, in general, the reverse speed is not over 20 per cent higher than normal running speed and is not dangerous from that standpoint.

In many installations reverse rotation of the unit causes little difficulty, but where sleeves are screwed on the shaft and pass through the packing gland, the builder usually makes the

thread so that during pumping the tendency is to tighten the sleeve against the impeller. If the glands are tight, then when the pump runs backward the sleeves may unscrew, and cases are not unknown where the pump has been damaged by breaking off the bearing bracket. With the sleeve unscrewed the impeller is not properly restrained from moving along the shaft and this further increases the danger of damage.

Pumping Plants

There are some unusual installations. one of which may be mentioned as an illustration. A very large-size pump with a vertical shaft was set up with 40 ft. of vertical discharge pipe, followed by a long horizontal line. The pump was nearly 20 ft. below the water in the well so that no priming was required, but there were nearly 800 ft. of suction pipe in which the velocity was 5.9 fps. at steady operation. It was inconvenient to place the discharge valve close to the pump, and it was actually installed just beyond where the horizontal and vertical pipes joined. There was no valve of any kind on the suction side. The installation is shown diagrammatically in Fig. 2, A being nearly 20 ft.

Following common practice, the motor switch was thrown in with the discharge valve closed, and just as the valve started to open when the pump was up to speed, a pressure shock cracked the pump casing. This might have been foreseen, because, when the pump was shut down with discharge valve closed, water in the vertical discharge pipe quickly fell to the well level, leaving a space filled with air in the discharge line between the well level and the valve. On starting the pump the air was compressed to about discharge pressure, and as the valve

began to open the air rushed out of line, allowing the water to reach full velocity in the vertical pipe. As the front of this column reached the partly open valve the velocity was largely ex-
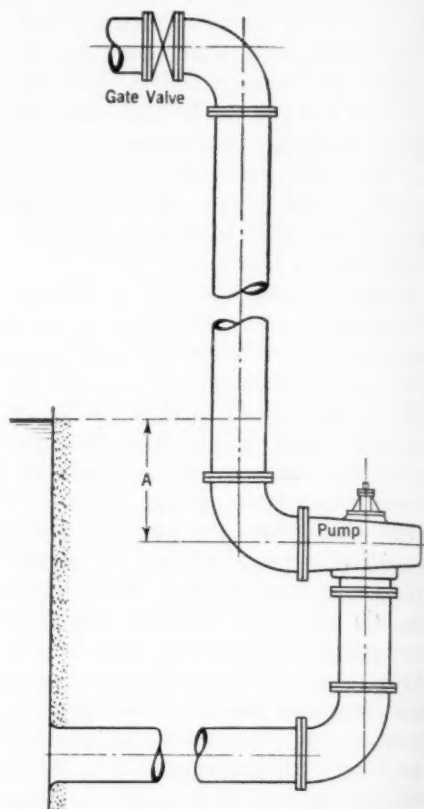
Fig. 2. Unusual Pump Arrangement That Resulted in Heavy Water Hammer Pressure Until Vacuum Pump Was Installed to Exhaust Air From Discharge Pipe and Fill It With Water Before Starting Up

tinguished and a heavy water hammer pressure resulted. Since it would have been very expensive to lower the valve, the only remedy was to put in a vacuum pump and exhaust the air, in order to fill the line with water before starting up.

The long suction pipe greatly complicated the problem, for the water

would be drawn from the pump end of it before the column could be sufficiently accelerated to supply the demand, and water hammer pressures would be set up in the pump from this cause. A well should always be made close to the pump to supply the water demanded while that in the intake line is being brought up to running velocity.

Pumps Working Together

Where several pumps are to work in parallel on the same line, their characteristics should be given careful con-
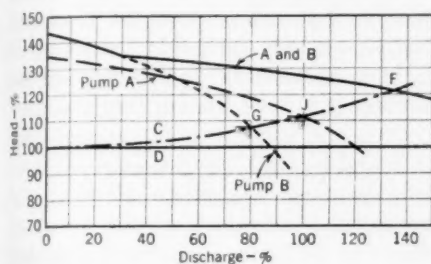
FIG. 3. Characteristic Curves of Two Pumps Operating in Parallel in the Same Station

sideration, otherwise their actual output may fall far short of the sum of their individual deliveries. In Fig. 3 are shown the characteristic curves of two actual pumps, A and B, in the same station, their individual normal operating points being indicated by G and J. If these two pumps are thrown on the line at one time their combined characteristic is shown by the plain curve found by adding the discharges of A and B at the same pressure in each case. The static head, corresponding to the tank level, is shown at D and the curve C indicates the dynamic head to be pumped against, the vertical distance between D and C corresponding to the resistance loss for the corresponding discharge.

It is to be noted that, while the sum of the separate discharges at rated heads is 180 per cent of the discharge of the larger pump, yet when both are put on the line at the same time the combined discharge at F is only 133 per cent of that of the larger pump, because of the increased pressure. Where the individual characteristic curves are flat, this decrease is greater than with steep curves, because a slight increase in pressure corresponds to a large decrease in discharge, but, on the other hand, a pump with steep characteristic at the normal output point has a rapid decrease in pressure for discharge above normal, so that other circumstances must be taken into account.

Propeller Pumps

Propeller-type pumps are being introduced to a fairly large extent to cover the field where the head is low and the discharge is large. Centrifugal pumps are used in this service, but must be run at slow speed and involve the use of a speed reducer or an expensive and bulky motor, whereas the propeller-type pump is relatively small and may be run at the speed of the ordinary motor. Its field of service is for drainage and sewage work and for pumping water up to water works filters, but the same type of pump is also used for deep wells because its small diameter enables it to be fitted inside ordinary pipe casing.

As so far developed, these pumps have the undesirable characteristic forms of curves, where the head and power at zero discharge and at full speed are higher than, and sometimes twice as high as, the corresponding quantities at rated discharge, and the curves generally have the reversed form. Usually the pressure is not high

enough to cause any trouble, but the high power means a correspondingly large torque on the motor, which the latter may not be able to produce. Therefore either special starting devices are necessary or the pump must not be brought up to speed with a closed discharge valve. With a check valve on the discharge and an open gate valve there, the head developed cannot exceed the back pressure from the line, and this is one method of starting used. Also a bypass is sometimes arranged around the pump, having a valve which may be opened so as to allow some water to flow through the pump, thus avoiding the zero discharge condition.

Deep Well Pumps

Deep well pumps must be as small in diameter as possible so that they will fit into the well casing, and for that reason they approach the axial-flow type with relatively small head per stage, although the high motor speeds somewhat compensate for this. However, for the higher heads many stages are used, and guide vanes are placed between each pair of impellers. Both open and closed impellers are used, but the latter are the more common. The driving motor is often placed at ground level, and the pump is usually submerged in the well water to avoid priming, but since these wells are sometimes 200 ft. deep, the driving shaft is long and has to be guided at various points at which rubber-lined guide bearings are often used with water lubrication. Some builders, such as Byron Jackson, couple the motor to the shaft as in ordinary installations, and the motor is therefore submerged in the well water and often below the pump.

Power failures on these pumps, where the vertical pipe is long, result in reverse flow through the pump and cause the pump to run in the reverse direction, but most pumps of this type are designed to withstand this without damage. However, the surges in the pipe during reverse flow of the water affect the pressures in the pump to such a degree that open impellers may be forced to pound down against the casing and wear somewhat rapidly. Some builders arrange a ratchet or a brake on the pump shaft to prevent the latter from turning backwards.

Where both motor and pump are submerged and completely enclosed, it is difficult to tell whether the electrical connections are such that the pump is running backwards, and in three-phase circuits it is well known that the connection for forward rotation can only be found by trial. If it is impossible to tell by visual inspection whether the pump runs backwards or not, about all that can be done is to read the discharge gage pressure; if this pressure at no discharge is very much below the normal working head on the pump, the motor is, in all probability, running backwards.

Summary

Noise accompanied by cavitation damage in pumps is frequent if the pumps are set high above the well level. The same results are noticed when the discharge is low due to either reduced speed or increased head. Foot valves and strainers on the suction inlets may also induce these troubles and should be avoided where possible.

Occasionally cavitation has seriously damaged impellers in less than two years but it is often quite possible to build up the damaged places and completely restore delivery and efficiency. Frequent inspection is necessary. In one case, an impeller was covered with

a thick coating of slimy material which much decreased the capacity. This pump was used partly for refilling the coagulating basins and was designed for about a 26-ft. head. When the water was low in the well its capacity fell off.

A number of operators have found that high suction lift decreases output.

Occasionally, noise in the motor gives the impression that the pump is at fault. Noise in the pump may frequently be greatly reduced by admitting air to the suction side, but this must be carefully controlled, as the capacity falls off rapidly as the admitted air increases. In some tests of one pump 4 per cent of air by volume reduced the capacity nearly 40 per cent.

Putting several pumps in parallel on the same line decreases the capacity of each in a way that varies with the pump characteristics. There is, of course, increased friction in the distribution system when more water is put through it, and, as this increases the head on the pump, there will be a corresponding decrease in discharge.

There is an objection to a common suction header for several pumps, as air may leak through the glands on the stationary pumps and interfere with those running. The suction pipe of each pump should run direct to the well.

Water hammer and pressure surges are common on lines having centrifugal pumps. Frequently, a pressure surge, lasting a short time, occurs when a pump is put into service. Power failures cause extensive pressure oscillations which have been greatly reduced by special types of check valves with

a controlled time of closure. Air chambers are not as satisfactory.

The shape of the profile of the discharge main greatly affects water hammer in the line after power failure. In the 48-in. line in Toronto, there is a point where the pressure drops much below atmospheric when power fails, and observations agree with the theory that the water column separates at this point. The use of a specially controlled check valve with 4-in. bypass has prevented a dangerous pressure rise when the columns re-unite; the purpose of the bypass is to fill enough of the space with water before the velocity of the returning column from the reservoir becomes high enough to cause damage when it re-unites with the part of the column coming from the pump. The actual maximum pressure rise is only about 35 per cent and is reached in about 50 seconds where the pipe velocity is low. The pump is about 4,300 ft. from the breaking point of the column and nearly 8 mi. from the reservoir.

Reversal of the pump after power failure has often been observed, but with no harmful results to the motors. A case has been reported, however, of an engine driving a centrifugal pump being damaged by running backward.

Aside from ordinary wear, the mechanical difficulties with pumps are not serious. Some pumps have excessive end thrust, and where this is taken up by ball bearings, the latter run hot. In one case, over-lubrication increased the heating. The bearings were easily cooled with a small stream of water. Hydraulic balancing of end thrust is satisfactory where the pump is running under normal conditions.

Control of Surge in Pipelines

By Charles F. Lapworth

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A contribution to the Journal

THE use of electrically-driven pumping equipment for water works purposes has shown that pressures generated in stopping and starting can far exceed the normal working pressures. Similar conditions occur when there is a failure of electric current leading to an involuntary shut-down of the pumping plant. The high pressures which are generated increase the likelihood of broken mains and affect the working of subsidiary apparatus such as chlorination equipment.

The conditions which give rise to these high pressures are sudden changes in the velocity of water flowing in the pipeline, which may occur on the following occasions:

(1) The stopping of the pump.

(2) The failure of electric power.

(3) The starting of the pump.

(4) The sudden opening or closing of a sluice valve in the pipeline.

(5) The slamming of a check valve fitted to the pump delivery immediately after the pump is stopped.

(6) The formation of a partial vacuum at some high point on the pipeline following a shut-down of the plant. High pressures result when the ruptured water column re-unites.

Tests have been carried out by the author at Stevenage and Macclesfield, England, to determine the pressures which may be generated in the delivery main leading from the pumping plants where no special surge control is provided. When pumping conditions had become stable, the current was cut off and the pressure fluctuations were measured by means of a pressure recorder. The pressure recorder consists of a synchronous electric motor driving a circular chart which makes one revolution every four minutes. The high speed of rotation enables quick variations of pressure to be followed accurately. Figure 1 shows the nature of the pressure fluctuations.

It is interesting to note that these fluctuations are in accordance with the elastic water column theory first put forward by Joukovsky. The pressure variations consist of alternate waves of high and low pressure which travel from one end of the pipeline to the other and then back again. The time taken to make the trip, which can be measured from the chart, gives the velocity of the pressure wave. In a large lake or reservoir, this is the velocity of sound in water, about 4,700 fps. Where, however, the water is contained in a pipe, the speed of the pressure wave is reduced by the elasticity of the pipe walls. In the present instance the velocity of the wave is 4,000 fps.

The magnitude of the pressure rise (h) is closely in accordance with the Joukovsky law:

$$h = \frac{av}{g}$$
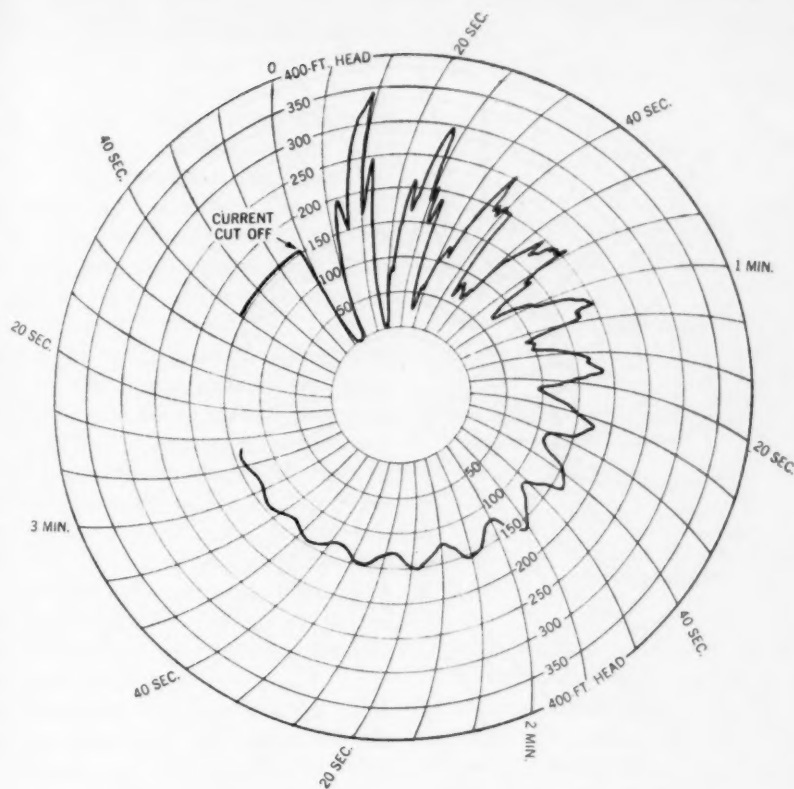
Fig. 1. Pressure Fluctuations With Uncontrolled Surge

where a = velocity of the pressure wave, v = original velocity of water in the pipe and g = acceleration due to gravity as modified by Schnyder to allow for pipe friction.

It will be noted that the pressure fluctuations gradually die away, and about three minutes after shut-down the pressure has become stable. This is the result of friction between the water and the pipe walls and within the body of the water itself which dissipates the original energy of the moving water column.

It will also be seen that immediately after the pump stops the pressure falls to zero. Inspection of an air valve close to the pump showed that the air was sucked into the main at this time, indicating that there was a vacuum pressure and that the water column had ruptured at this point.

The plant was fitted with a motor-driven sluice valve to control the surge, which, for the test mentioned above, had been put out of action.

The motor-driven sluice valve consists of a small electric motor operating a small pump which is used to generate oil pressure. This oil pressure is used to open or close the valve. The valve was made to give a closing time of three minutes. When stopping the plant, the closure of an electric switch brings into operation the motor-driven valve, thus causing the valve to close.
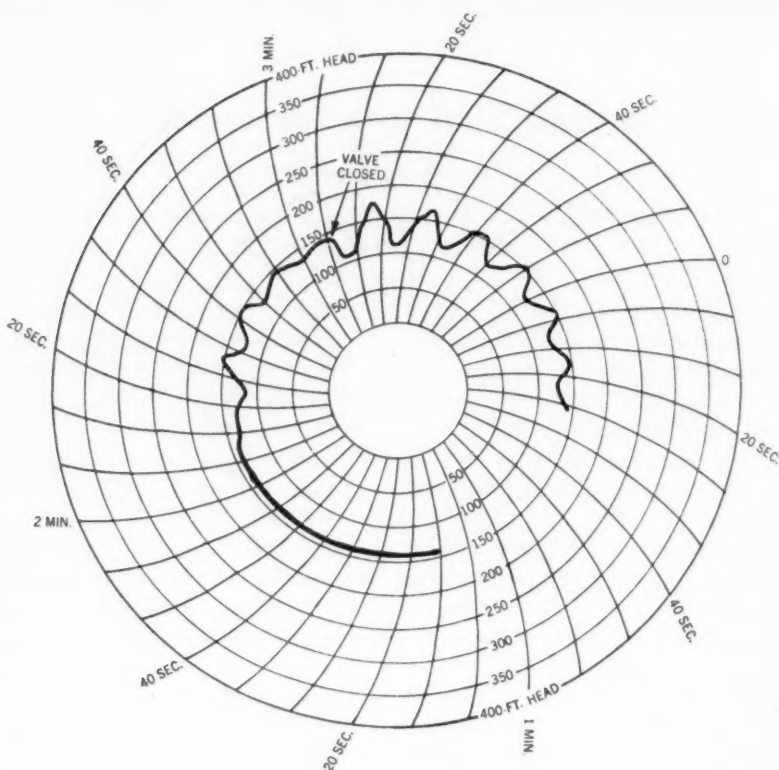
FIG. 2. Pressure Fluctuations With Surge Control

When the valve reaches, or almost reaches, its seating, an electrical contact cuts out the main motor driving the pump. By this means the water column is retarded slowly.

Tests were carried out with this valve in operation.

When the diagram, Fig. 2, which shows the nature of the pressure fluctuations, is compared with Fig. 1, it will be seen that the fluctuations are less violent, that a vacuum pressure is prevented and that the maximum rise in pressure is reduced from 200 to 40 ft.

The normal type of check valve as fitted to the delivery side of a centrifugal pump works satisfactorily with the sluggish type of water column consisting of a long main under relatively low head, common in water works practice. Where, however, the column is more mobile, shock pressures may occur following the rapid reversal of the water column after the pump stops. The ideal check valve would reach its seating at the exact moment that the water column is at rest, that is, before reversal occurs. With the more mobile columns, however, the water column reverses before the valve is closed, thus causing the valve to shut. Tests were made on this plant, using a check valve with the normal type of flap. The tests showed that this could cause very high shock pressures with audible water

hammer. The oscillations were so violent that the pen was thrown off the chart of the pressure recorder, but it is certain that the pressures exceeded three times the static head, or over 500 ft. The reflection period of the pipeline is six seconds. The flap of the check valve closed about $\frac{10}{11}$ seconds after the pump was shut down, that is, during the period of the first pressure rise.

When the valve in the bypass around the check valve was opened, the pressure rise was reduced to that shown in Fig. 1, which is closely in accordance with the Joukovsky theory, indicating that the slamming of the flap was responsible for the excessive pressure.

Where these conditions occur, the remedy lies in the use of a check valve of a more scientific design, or in the use of one of the surge control devices to be mentioned later.

The problem of surge control is to vary the velocity of the water column more slowly or, alternatively, to dissipate the energy of the moving column of water harmlessly. Control may be achieved by any of the following methods:

(1) *Fly-Wheel.* It is noticeable that surge pressures are not developed to anything like the same degree with pumping plant using an oil engine as a prime mover. This is because of the high inertia of the moving parts of the prime mover. In some instances a flywheel has been added to electrically-driven equipment in order to add to the inertia of the moving parts and thus cause the pump, on stopping, to slow down more gradually.

(2) *Motor-Driven Sluice Valve.* In suitable circumstances the motor-driven sluice valve can be effective in reducing surge pressures to reasonable limits.
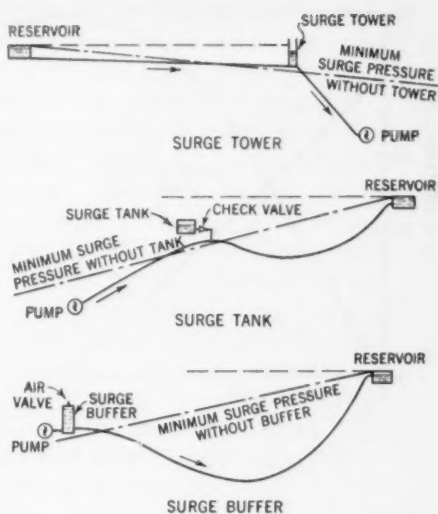
FIG. 3. Use of Surge Tower, Surge Tank and Surge Buffer

(3) *Delayed Action Stop/Start.* This device consists of a series of electrical resistances placed in the starter circuit of the motor driving the pump. A small electrically-driven motor is used to drive a shaft carrying a number of cam type contacts. These contacts are connected to the electrical resistances, the effect being that the speed of the pump motor is increased or decreased more slowly.

In the case of water works equipment at Eddisbury, England, which consists of a vertical spindle centrifugal borehole pump, excessive surge pressures were generated on starting the pump. A delayed action device was fitted to give a 30-second interval between full speed and complete stopping. No further trouble was experienced with surge.

(4) *Pressure Relief Valve.* The relief valve is normally fitted to a tee branch on the pipeline. The device consists of a valve held against its seat by a spring or weighted arm. A rise
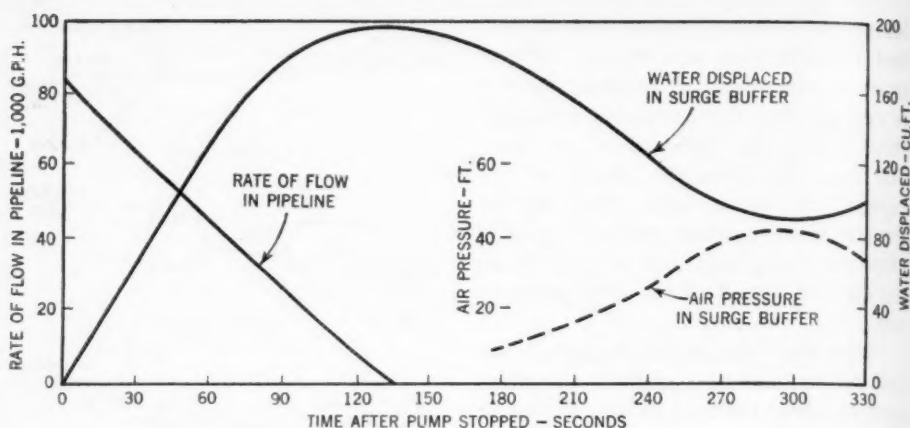
FIG. 4.　Test on Surge Buffer

of pressure in excess of the pre-determined amount causes the valve to open and the water to be passed to waste. Where the buildup of pressure is very quick, however, it may sometimes happen that the valve does not operate sufficiently quickly to permit the relief of pressure. The useful application of the pressure relief valve is, therefore, limited to cases where the pressure rise is moderately slow.

(5) *Surge Suppressor.* The surge suppressor is a relief valve in which the port of the valve is arranged to open before the rise of pressure occurs. This is achieved by making use of a period of subnormal pressure to open the valve by hydraulic means. The surge suppressor, therefore, is suitable only where subnormal pressures occur before the pressure rise, such as for the protection of the delivery main against sudden shut-down. Surge suppressors are in common use in the U.S.; some of these have been used for very high heads up to 3,000 ft. At the Hoover Dam for the Boulder City water supply the fitting of surge sup-

pressors reduced the pressure rise from 400 to 120 ft.

(6) *Air Vessel.* An air vessel consists of a steel cylinder connected to a branch on the pipeline. The vessel is partially filled with air, the small loss of air by solution being made good by a small electrically-driven air compressor. The effect of the air vessel is to damp the surge action by the elasticity of the air in the vessel.

At high points in the pipeline it sometimes happens that the effect of starting or stopping the pump is to cause cavitation or the formation of a partial vacuum in the pipe. Where this is likely to occur, the following control devices may be of use.

(7) *Surge Tower* (Fig. 3). It is common in hydro-electric installations to provide an open surge tower on the inlet pipe to the turbines. The tower acts as a reservoir to provide the extra water required when the turbine gates are opened. It also provides an outlet for the water no longer required by the turbines when the gates are closed. As far as is known, the surge tower

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has not been applied to water works installations.* There would seem to be no reason, however, why this should not be done in suitable cases, particularly where the pipeline lies near the hydraulic gradient.

(8) *Surge Tank* (Fig. 3). This device consists of an open tank connected to the pipeline by a branch pipe carrying a check valve. When the pressure in the main falls below the level of the water in the tank, water flows from the tank into the main. On the subsequent rise of pressure, the check valve closes, thus preventing the tank from being flooded.

A pipe of small diameter connected to the pipeline and controlled by a ball valve is used for re-filling the tank.

(9) *Surge Buffer* (Fig. 3). The surge buffer is a development of the surge tower, but, being a closed vessel, is not confined to places where the pipeline lies near the hydraulic gradient.

A surge buffer has been fitted to a water works pumping plant at Crewe,

* This "surge tower" principle was put into practical use at the Springwells filter plant in Detroit in 1931.

England, for the protection of a delivery main 15 mi. in length operating under a low static head of 25 ft. The buffer consists of a vertical steel cylinder inserted in the pipeline close to the pump. At the top of the cylinder is a special air valve. When the pumps are running, the surge buffer is filled with water, any air being expelled automatically through the air valve.

When the plant is shut down, water in the buffer flows into the main to take the place of the water which has gone forward away from the pump. When this happens, the air valve at the top of the buffer opens, thus admitting air into the cylinder. On the return surge of the water column the large aperture of the air valve closes, thus trapping the air in the cylinder to form a cushion or buffer. Air is gradually blown off through a small aperture in the air valve until all the air has been replaced by water. The operation is thus entirely automatic. As shown by tests carried out by the author (Fig. 4) the buffer has been completely successful in preventing cavitation in the pipeline and excessive surge pressures.

Customers' Complaints As a Guide to Better Service

By M. Warren Cowles

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Presented on Nov. 3, 1944, at the New Jersey Section Meeting, Atlantic City, N.J.

IT is assumed that the water leaving a plant is of safe quality, reasonably free from taste, odor and sediment; that there are adequate records of the distribution system, showing size of mains, location of valves and services and materials used; and that records of customer complaints are kept. It is further assumed that such complaints are not taken for granted but are approached with an open mind. It is both the avoidance of and the solution to the problems which cause such complaints that this paper will undertake to discuss.

Corrosion and Red Water Complaints

Corrosion is always active to a greater or lesser degree in a distribution system; yet, under normal conditions, there may be little visible evidence of it except with the appearance of red water troubles and, perhaps, excessive sediment in certain areas. Information concerning such appearances is likely to be derived only from customer complaints. Corrosion may occur in the distribution system or in the service lines, if the pipe is poorly protected or if two or more metallic substances have been employed, causing galvanic action. Or the water may be, from the time it leaves the plant, of such a corrosive nature that rectification lies in treatment of the water itself.

Combating Corrosion by Protecting the Pipe Surface

Much research has been carried on to find adequate coatings for cast-iron pipe. Old pipe may be relined in place. New cast-iron pipe often needs better protection than afforded by the present tar coating put on at the foundry. The rough surface of pit-cast cast-iron pipe makes protection with a thin coating material difficult. Cement lining protected by a tar coating seems to be the best method available at present for cast-iron pipe of 12 in. or less.

Regardless of the practicability of any particular coating, the problem arises of the best point of application. Coatings may be applied at the foundry, at the water works storage yard or on the site of installation. Cost and the possibility of damage in transit or in storage are the factors to be considered. Cement lining and tar coating of pipe 12 in. or less seem to be most practicably performed at the foundry. The over-all cost of such pipe is somewhat greater but the advantages more than justify the added expense.

Combating Corrosion by Treating Water at the Source

Treatment of supplies at the source to decrease the rate of corrosion in the distribution system is feasible. Frequently, however, particularly in New Jersey waters, protection by this

method can be obtained only by raising the pH of the water to so high a value that too much mineral matter is introduced. In some well supplies, this treatment might involve extensive rearrangement of pumping station facilities.

Progress has been made in the development of more effective treatment materials than are now available. The chemical industry is working on such substances as the phosphates, silicates in combination and sodium tetra-phospho-glucosate. These and other materials should be inexpensive and simple to apply.

Combating Corrosion by Correcting Electrolytic Conditions

Electrolytic corrosion may arise from the use of a variety of metals in one system. Many water works have installed ferrous metals, copper and copper alloys (brasses and bronzes) with little attention to the fact that dissimilar metals connected and immersed in water will cause corrosion at a rapid rate by galvanic action.

Such use of heterogenous materials is uneconomical because it shortens the life span of pipe, but the principal trouble encountered in the water works operator's immediate sphere is the appearance of sediment and discolored water on customers' premises, producing the usual complaints in the water company office.

Water is a universal solvent. Even the so-called "pure" metals are dissolved in varying degrees. The presence of very small amounts of impurities in nearly pure metals may greatly affect the durability of the metals. For a time, a good deal of trouble was derived from washing-machine parts which were die-cast from zinc alloys. Some copper pipe will develop a tena-

cious corrosion-resistant scale and other pipe in the same line may have a soft, easily-displaced scale which will expose the metal to corrosion and cause a greenish or bluish sediment in the water.

Inside piping presents much the same picture as the distribution system, and usually service pipes, in older buildings and even in new construction, offer an even greater assortment of materials. The water drawn from a customer's tap is affected by piping on his premises as well as in the street. The fact that the physical quality of water may vary from house to house along one street suggests that greater uniformity in metals used in water pipe systems is desirable and necessary, although all the factors in this problem are not yet known, and it is not a simple matter to achieve such uniformity.

Parts of interior piping are subjected to wider ranges of temperature than are underground pipes. Insertion of brass or copper pipe in a galvanized-iron piping system of older buildings will usually greatly increase the rate of corrosion of the iron pipe, making complete replacement necessary sooner than if a piece of iron pipe had been inserted. Similar acceleration of corrosion may occur, though not invariably, when a galvanized-iron hot water tank is connected to lengths of brass or copper pipe. Poor workmanship in making threaded joints on brass pipes also may contribute to corrosive action.

The use of insulating couplings between dissimilar metals may help to prevent damage by galvanic action. There is also a need for increased cooperation between plumbers and plumbing inspectors and the water works industry on the matter of inside piping.

Stray electrical currents of normal magnitude may also be a factor in elec-

trolytic corrosion, but the widespread practice of using dissimilar metals has made it difficult for researchers to determine to what degree such currents enter into the problem.

There is a large area of undiscovered information on this subject and customers' complaints might be explored for guideposts. Manufacturers are keenly interested in these problems, but have been unable to obtain authoritative data. The water works operator can be of assistance to them by carefully investigating customer complaints.

Combating Corrosion With New Materials

It is possible that manufacturers may develop for postwar promotion a cast iron more resistant to corrosion than is the present formula. This may be achieved by the introduction of other metals in small amounts, or by special heat treatment. It is hoped that it will be possible to machine this new material for working parts of valves and other items.

Service pipe corrosion problems may be overcome by the use of the special cast-iron alloy pipe with valves of the same material, by the use of insulating couplings at several points in the service line or by the use of non-metallic piping materials, such as asbestos-cement and the various types of plastics developed during the war years.

Well-known and relatively inexpensive materials (steel, for example) can be made more acceptable if provided with new lining materials utterly different from lead or from the present process of galvanizing. Plastics may possibly be among the materials used.

Corrosion of the materials now used in water meters has precipitated many customer complaints. The changes re-

sulting from wartime controls over critical metals have not been too serious and it may be found that they were definitely efficacious. There have resulted stimulation and renewed interest on the part of the manufacturers, which may produce some healthy results and which need encouragement. Certain fundamental conceptions should probably be changed. The buyers of meters may pose the questions: Is the frostproof bottom adequate? Are there other improvements needed which I, as a user, might suggest to the manufacturers?

Ordinary galvanized-iron hot-water tanks produced during the war years may present problems. They are less durable because the galvanizing is altered in content; the coating looks much brighter and shinier. To maintain a hot water temperature much over 140° is to court trouble, for the corrosion rate is greatly accelerated after that point is reached. New and better devices for temperature and pressure relief can be designed and should be located over a plumbing fixture, so as to prevent water from spilling onto the floor. No outlet piping is needed if such provision is made.

Bronze and copper alloys that are ordinarily very resistant to chemical corrosion have been used in hot water tanks, but here again the alloys have reacted peculiarly and with an apparent lack of uniformity.

Water in hot water tanks may be treated with sodium silicate and other substances to cut down corrosion of tanks and piping. Such procedure is particularly adapted to large buildings. Better methods of protecting hot water tanks are needed. The use of insulating couplings has already been mentioned. However, such practice is simple for use with a small tank but

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difficult in the case of a large steel tank with copper steam-heating coils. Tank linings of glass and other substances are being investigated and hold some promise.

Backflow or Back-Siphonage

Some water purveyors have become dangerously complacent regarding conditions on their customers' premises, perhaps because no serious outbreak of water-borne disease has occurred in their respective territories. Others have magnified the hazard. Unless customers request the water purveyor to investigate possible deterioration of water on their premises, the water purveyor is usually unaware of the conditions which may exist. Thus this situation may get scant attention.

Many things may happen. Interior piping in a house can be so badly corroded that a heavy flow of water in the cellar will produce a vacuum on the second floor of a house. In larger buildings, this is extremely serious. In addition, vacuums may result from a number of other possible conditions and, where a vacuum or a reduction of pressure is produced, back-siphonage from fixtures or water-connected devices may occur, resulting in contamination.

However, although back-siphonage does occur oftener than is realized, there are few cases of illness or stomach upset on record directly traceable to it. They certainly are not reported to the health departments, or more would be heard about them. It is, therefore, important to have good customer relations, so that consumers will request investigations if they note any peculiarity in the delivered water. Lack of exact data may cause indifference or may be used to magnify the problem far beyond its true size.

Therefore the customer with his complaints can help the water works operator to find the true solution.

Backflow connections (not including cross-connections) will permit back-siphonage from plumbing fixtures and other water outlets to tanks, vats, sewers and drains.

Not much progress can be made in the matter of backflow connections until the major number of outlets on a water piping system in a building (e.g., plumbing fixtures) can be protected. As a result of some four years work by a committee on plumbing standardization (A-40) of the American Standards Association, standards for air gaps were developed and issued by the ASA in 1942. A large majority of new faucets now manufactured are not siphonable except where used with some obsolete types of fixtures. Here is one definite national advance in the complex problem. The backflow preventer design and performance standards were set up by the same committee and published by the ASA in 1943. These two standards have been very helpful. The manufacturers of plumbing goods generally have been exceedingly co-operative in making the new designs available, even though it has meant changes in the manufacture.

The above standards refer, of necessity, to protection against backflow at water outlets either by air gaps or by a mechanical or a non-mechanical backflow preventer. Most water works operators insist that the air gap is the only safe method but in some cases preventers may be installed on a conditional basis, for even though they have been used for many years, they are still mechanical devices and liable to failure. They can be tampered with. In each municipality a ruling on this question should be made co-operatively.

In New Jersey, backflow connections are not covered by a state law. Control of them is left in the hands of individual municipalities.

The National Plumbing Laboratory, established several years ago, has accomplished much in examining control valves and water-connected devices with the hope that their findings would secure nation-wide acceptance, and eliminate, in part at least, conflicting reports of other testing agencies. To secure protection against back-siphonage, radical changes in some designs submitted were made. Some 40 valves and devices were approved.

The National Association of Master Plumbers has been active in educating its members and the general public regarding the hazards of other backflow connections.

The war limited the availability of brass and bronze for use in flush valves and plastics were substituted in some of the working parts with not too good results. Customer relationships may help to locate these difficulties.

Cross-Connections

Water purveyors in general are going to have more difficulty in securing elimination of cross-connections by separation as a result of temporary wartime changes. Fundamental conceptions may be seriously shaken when confronted with some of the devices other than double check valves which have been installed throughout the country to protect cross-connections as a result of wartime requirements.

Customers usually do not volunteer the information that cross-connections exist on their property, and many water plant executives might be surprised to learn how many are extant in the areas they serve. Such a condition has appeared on the Pacific coast and in other areas where there has been extensive war plant construction and expansion.

When the consumer gets in trouble with actual or suspected contamination, he notifies the water department, and it is then that the operator has an opportunity to act. He should investigate the number of auxiliary supplies in the territory served and determine the number of cross-connections. He should decide how to discourage the re-installation of the cross-connections after they have been removed. A policy should be formulated for all classifications of cross-connections, keeping in mind that for cross-connections 4 in. or less in diameter, double check valves are not a reliable means of protection against backflow.

Cross-connections in the fire protection systems of large industrial plants may come about by reason of the present requirements of fire insurance companies for a dual source of supply on sprinkler systems. Co-operation with the customer in such cases is of the greatest value. Newer methods of putting out fires by fog nozzles, carbon dioxide gas and several other possible systems are proving valuable. Their advantages may possibly effect a change in the present insurance company requirements for dual supplies.

Water purveyors in other states may find guidance in the cross-connection law of New Jersey, the author's state (Chap. 308, P.L. 1942).

Avoiding Sluggish Circulation and Dead Ends

A common source of customer complaints is the existence of sluggish circulation and dead ends in outlying districts. Sluggish circulation results in the appearance of bacterial aftergrowths and related effects, of which the customers' complaints should promptly ap-

prise the operator. Chloramination, and in some cases super-chlorination, will contribute to the surmounting of these difficulties. Other sterilizing chemicals will doubtless be available in the post-war period and perhaps they will also be toxic to lower forms of bacteria and protozoal life.

As a distribution system is extended, plans should be made to avoid the creation of permanent areas of sluggish circulation and dead ends. Local planning boards and municipal officers will help in securing proper layouts of the streets in new developments. Perhaps there should be a re-examination of the use of small mains for residential customers and provision for adequate fire flows for hydrants located on larger mains. Installation costs for water mains may remain at present levels for some years to come and therefore double building lines should be considered. This is particularly important in the light of the new low-cost methods of housing production now being evolved. Land costs and all development costs will come under close scrutiny by the builders of such low-cost housing.

Radio for Improved Service

Radio in various forms, perfected for wartime purposes, will enable a super-intendent to maintain contact with his men wherever they are, whether in car or on foot. This will improve water works operations and functioning and thus improve service to consumers.

Conclusions

Only when the water works operator realizes that customers are sometimes dissatisfied with the water they get and the operator in turn becomes dissatisfied with existing conditions will he begin to explore new fields and avoid old pitfalls. The operator must be ready to accept the advantages of new ideas, new methods and new materials and weigh the advantages impartially against the disadvantages which may appear. As a group and as individuals, the members of the water works brotherhood must better understand the problems involved on customers' premises, the sizing of water piping and tanks, the effects of the installation of water-connected devices, backflow conditions of all types and the conditions under which backflow occurs. There is no clear and definite road to follow. The path is full of "booby-traps." By sincere exploration of customer complaints and co-operation with other agencies in finding solutions, much can be accomplished.

Politics and Public Service

By Willard Chevalier

Vice-Pres., McGraw-Hill Publishing Co., Inc., New York, N.Y.

At the meeting of the Executive Committee of the A.W.W.A. held in New York on June 29, 1945, Honorary Membership certificates were presented to Messrs. George W. Booth and Willard Chevalier. Mr. Chevalier's impromptu but brilliant response was recorded by the stenotypist and is herewith published in the JOURNAL *for the benefit of all its readers. The concept expressed by Mr. Chevalier, that politics (in the proper meaning of the word) and public service are essential each to the other, will elicit affirmation from experienced and successful administrators of public water supply properties.*

Samuel F. Newkirk Jr., President of the Association, introduced Mr. Chevalier with these words: "Mr. Chevalier, I once heard you remark that there were two things that could not be taken out of water. One was salt and the other was politics. A global war has produced, as we all know, desalting kits. I wonder what sort of an upheaval would be necessary to remove politics."

What your Chairman said about the place of politics in water makes it incumbent upon me, I think, to extend that comment.

We in this country have come to invest the word "politics" with a highly unpleasant connotation—one that is both inaccurate and unfair. Without politics, there can be no democracy. Without politics, there can be no great business corporations, no great associations of individuals engaged in any sort of co-operative endeavor. "Politics" in its true sense derives from the word "polity," and that, in turn, goes back to the principles and the measures that make it possible for men to work together in their common interest. Whenever you bring together more than one person with purpose to work to a common end, you must have of necessity a compromise of interests— you establish a polity and you must practice politics.

As more and more people thus work together and as their interests become more vital and far-reaching, the compromises become more numerous and more searching with respect to the life and the interests of each individual. I do not believe we shall ever get politics out of water or out of anything else that is sufficiently important to justify community of effort on the part of large numbers of people. So we have governmental politics, association politics, industrial politics, lodge politics, even church politics.

The only reason for this extension of my thought on the subject is that, in my judgment, we are going to have more politics in the future than in the past. Our concern, therefore, is to see that we raise our politics to a higher plane than they have attained in the past and that we keep them on the highest possible plane most of the time.

I am one of those who are convinced

that the relations between the people and their governments are going to be more comprehensive and more intimate than they ever have been. I think that government is going to have more to do with individuals, with business and with industry than ever before.

Certainly, the kinds of community services of which water supply is typical are going to become more and more significant. They are going to demand the attention and touch the interests of more and more of the people. That means that the politics of water and of public service in every department are to be of increasing importance.

It seems to me, therefore, that the chief tenet of our politics should be to get more and more of the people to know and to understand and to participate in the conduct of those community activities. So long as we have public servants living in a world of their own, wrapped up in their own particular bureau politics and in the politics of the party that happens for the moment to be in power, just so long will our politics be on a low level. But the more we can get the whole life of the community into those activities, the more shall we raise the level of our politics; because more of the people will be interested and take a lively interest in what goes on.

I hope that I shall live long enough to see the taint that now attaches to politics removed from the minds of our people. I have lived and worked close enough to politics to see its seamy side as well as its brighter side. In my judgment, community service is on a higher plane today than at any time within my knowledge.

The type of man who is serving our community facilities today is higher than it ever was. Certainly his technical competence is higher than it ever has been. I believe his aspirations

are higher than they ever have been.

Considering the life of this Association, we all know how steadily it has climbed in its own conception of the job it has to do. The men who come after us who are here today will have still higher concepts. They will look back to what we now think is pretty good and they will say, "Well, those fellows were certainly on the way up, but from our vantage point they don't appear to have gotten very far at the time they were working."

This is as it should be. If there is any hope at all for democracy, we shall find it only in a growing sense of civic honesty and civic responsibility, and that is bound to appear, first of all, among the men who are elected or selected to serve the people.

I remember a time when a "government job" was not looked upon as being very much other than a job. The idea of a career in public service was tied up with the idea of getting a political pull and of keeping it effective.

That still is true in some quarters. But more and more we recognize and honor men who, going into public service during that period, were primarily concerned with rendering faithful service and were not a bit concerned about "getting in right." More and more we have seen those men reach the top in public service because the civic conscience has been rising as they came along. And because of the high standards they set, high-grade men today are finding it less and less necessary to cultivate that "get-in-right" quality and more and more necessary to do the kind of job that the public has a right to expect.

Our only hope lies in our ability to maintain that trend. And associations such as this one can have no more vital objective than to nourish and strengthen it.

Promotion of Fraudulent Water Purifiers

A device, which comprises two electrodes and which is represented to treat water electrically upon immersion of the electrodes into the water to be treated, has been offered for sale intermittently in one place or another over the country for at least 25 years. One of the latest episodes of this sort was recently investigated by the Indiana State Board of Health and the results of its report published in the July 1945 Bulletin of the Indianapolis Better Business Bureau. The Bulletin's story, reprinted by permission of the Indianapolis Better Business Bureau, follows:

The "Aquatron" is a widely sold device on the representation that it is a water purifier. It might be briefly described as a gallon glass jar or jug with a screw top in which are fastened two electrodes. Both electrodes are of aluminum. When the jar is filled with water, the electrodes are connected to a house current thus "purifying" approximately one gallon of water. When called to the Bureau's attention it was being sold by "Brown's G & W Health Food Store." . . .

The printed literature issued in connection with it states that it is manufactured by the Kruse System, Inc., of Indianapolis.

A Health Aid

A shopper went to the store to see what representations were made concerning it. The shopper was informed that the city water we are drinking is at no time completely pure, and that sometimes it is practically untreated; that each week human bodies, such as suicides, and animals fall into the canal, which decompose and add to the impurities of the water we are drinking; that by buying the little gadget known as the "Aquatron" at $37.50 each, pure water thus obtained would be worth many times the price by protecting one's health.

Demonstration

The salesman then conducted a demonstration. He placed the "Aquatron" in a gallon jug of city water and connected the plug to a wall outlet. Immediately small white particles began to form and drop to the bottom of the jug. The salesman claimed that such particles were the filth in the water, and when the electrodes were removed, such bacteria would die and eventually sink to the bottom, leaving the clear purified water on the top.

In the literature given all buyers or potential buyers of the "Aquatron," the claim is made that such device is constructed to remove "all harmful bacterias, chlorine, filth and all suspended matter, leaving the pure *organic mineral* matter which is essential to cell life." In the same pamphlet it is also claimed that the "Allied Governments of World War II are using the Aquatron method of water purification in all theatres of war to give our boys PURE DRINKING WATER."

Further the literature claims, "Eminent physicians throughout the world agree that thousands of people could be spared the suffering of such diseases or ailments as rheumatism, arthritis, diabetes, headaches and all kidney disorders, together with a host of many

other ailments which are too numerous to mention," the inference and the context meaning to the reader that the Aquatron would be a relief to such ailments.

Laboratory Tests

After learning from various sources such statements were being made concerning the device and the impression left that the city water was impure, the Better Business Bureau was interested to discover exactly what the merit of such water purification device was.

A series of experiments were conducted for us by the laboratory of the Division of Environmental Sanitation of the Indiana State Board of Health. In carrying out such investigations, the device was operated strictly in accordance with the directions accompanying such instrument. A number of water samples were examined both chemically and bacteriologically before and after the "Aquatron" treatment in order to determine what changes had been produced and to ascertain how true the claims were. Since the report is very extensive and of a complex scientific nature, no attempt is made here to present all the factual data surrounding such experiments. Following are the conclusions reached:

First: A city water sample was scarcely changed either bacteriologically or chemically. The sample met standards of the Indiana State Board of Health both before and after treatment. Absolutely nothing was gained by the use of the "Aquatron."

Second: A water sample containing gross pollution was improved bacteriologically due to the effect of the precipitate formed while the device was operating. The water, however, was by no means sterile after the treatment, and certainly would not be called safe for drinking purposes. No particular change took place chemically.

Third: A water sample containing a moderate amount of pollution is improved somewhat bacteriologically, but again the chemical results show little difference before and after the use of the "Aquatron."

Fourth: The white precipitate which is observed on all experiments after the machine has been operated for the specified length of time does not come from the water (claimed to be filth by the agent selling such device), but is from the action of the current on the electrodes. The precipitate is a hydroxide of aluminum formed by the action of the electric current on the electrodes, which apparently are aluminum or an alloy of aluminum. Experiments revealed that the water contained no aluminum before the tests, but contained some at the end.

Fifth: A claim is made that the chlorine is removed from the water during the "Aquatron" treatment. One of the experiments showed that the free chlorine was not removed, but reduced slightly, which could have been due to the effect of the aluminum hydroxide absorbing the chlorine while settling. Again, removal of the chlorine is not a point of merit because it is a very common recommended practice to maintain some residual chlorine in a public water supply at all times.

Sixth: One test showed that the same results could be accomplished by using a slight amount of filter aluminum sulphate.

Seventh: It was noted that the same visible action observed in the use of the "Aquatron" could be produced by merely placing two aluminum strips into a sample of water and attaching these to an AC current outlet.

The results of all these experiments showed that the claims concerning the action of the "Aquatron" are not substantiated. Very little change takes place in the chemical content of the water, and the "Aquatron" is vicious in that it does not purify impure water

sufficiently to make it safe for drinking purposes. Also, the operation is dangerous because of the explosion hazard, particularly if only a small amount is being treated, leaving space above it in the jar for the oxygen and hydrogen to collect. It is amusing to note that while the salesman himself was operating such device in the G & W Health Food Stores when he removed the cover from the jar before pulling the plug from the outlet, there was a loud explosive noise.

No justification for its use on the ordinary public water supply is noted. From several expert sources it was also determined that a unit comparable to the "Aquatron" could be produced at a cost of somewhat under $5.00, which price would include material, labor and transportation.

We have been assured by an executive of the Kruse System that they did not authorize the oral representations made by the salesman in this instance; also that they will withdraw all literature now using such representations; and that they will destroy and not distribute some fifty thousand pieces of present literature on hand; and that they will either withdraw the "Aquatron" from the market, or sell it for some other purpose or in some other manner.

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Elimination of Midge Fly Larvae With DDT

By Martin Flentje

San. Eng. Dept., American Water Works & Electric Co., New York, N.Y.
A contribution to the Journal

DDT, applied for the first time (so far as is known) to a potable public water supply, was recently found effective in eliminating an infestation of midge fly larvae at Alexandria, Va., which is served by a subsidiary of American Water Works and Electric Company. A dose of 1 part DDT in 100,000,000 parts of water (0.01 ppm.) was applied on Aug. 31, 1945, and was found effective in eliminating these pests. The offending organisms, identified as belonging to the Chironomidae family (also called Tendipedidae), were demonstrated in laboratory tests to be typically resistant to copper sulfate and high chlorine dosages. The organism present was fortunately not of the common "blood-worm" type, but was instead colorless to faint green and it was short—4 to 5 mm. in length. Movement was with the characteristic figure-eight motion typical of these larvae.

The source of the infestation was the two clear water storage reservoirs (capacity, 16.5 mil.gal.) located at the Alexandria Water Company's filtration plant.

The use of DDT was first suggested to the author by Sanitarians English and Slaymaker and Dr. Shrop, Head, all of the Alexandria City Health Department. Before proceeding with the application, numerous authorities on entomology and public health were consulted, either directly or through one of those named. Among them were Doctors Dove, Bishopp and Lindquist. Entomologists of the U.S. Department of Agriculture; Dr. Calvery of the Pure Food and Drug Administration; J. K. Hoskins of the U.S. Public Health Service; and Richard Messer, State Sanitary Engineer of Virginia.

A dosage of 0.01 ppm. DDT killed these larvae in approximately eight hours under laboratory conditions; kill was also obtained in somewhat less than sixteen hours with a dose of 1 part in 200,000,000.

On August 31, 0.01 ppm. DDT made up in Triton X and Xylene (25 per cent DDT) was diluted with water to an emulsion strength of approximately 1 per cent and this was sprayed on the surface of the reservoirs with a civilian defense stirrup pump. A boat with an outboard motor was employed and the wake of the boat was used for mixing and diffusion. Three to three and one-half days after this treatment the larvae disappeared from the distribution system.

Alexandria, Virginia—Survival and Retirement Experience With Water Works Facilities

As of December 31, 1940

THE privately-owned Alexandria Water Company serves the city of Alexandria, Va., and adjacent territory. The 1940 population of the city was 33,523.

Alexandria is located on the Potomac River in the northern part of the state, about 7 mi. south of Washington, D.C. It was first incorporated in 1749. In 1850 it had a population of 8,754 and grew very slowly until the late twenties, when, because of improved transportation facilities, it benefited greatly from the population overflow from Washington. As a result the population has more than doubled in the last fifteen years and it is continuing to grow rapidly.

The territory served is predominantly residential but there are a few scattered industries. The Potomac Yards, one of the largest freight classification yards in the country, is located at the city's northern limits.

As of Dec. 31, 1940, the date of this study, there were 8,181 consumers, about 55 per cent of whom were served through meter measurement. There were 87 mi. of mains. The average pumpage in 1940 was 3.23 mgd., equivalent to 81 gpd. per capita. About 5 per cent of the water served was for industrial use. Not included in the above is the sale of untreated water to the Southern Railway which amounted to 118 mil.gal.

Development of Existing System

The Alexandria Water Company was incorporated in 1851 and the plant was built in 1851–1852 and put in service in June 1852. The construction was done under the direction of an engineer who had previously built the water works at Harrisburg, Pa., and Fredericktown, Md.

The company was financed by local capital and continued to operate under local ownership and management until 1929 when the capital stock was acquired by the American Water Works and Electric Company, Inc., under whose ownership and management it continues in operation.

The original works consisted of a pumping station at which water was pumped to a 2.5-mil.gal. storage basin from which it was delivered by gravity to consumers through 7 mi. of cast-iron pipe.

The source of supply was Cameron Run. Water from this source was diverted from the stream by a diversion dam below the junction of its tributaries, Holmes Run and Back Lick Run. There were no impounding facilities on the watershed, the natural flow of the streams being sufficient for the requirements at that time. From the diversion dam a race some 9,000 ft. long conveyed the water to the pumping station. The race delivered water

TABLE 1
SUMMARY OF WATER MAINS
ALEXANDRIA, VIRGINIA

Size, in.	Kind	No. of Feet Identified*	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, yr.
4		97,978	21.6	1,425	6.9	96,553	22.3	1852	48.2
6		125,650	27.7	1,658	8.1	123,992	28.5	1852	28.8
8		30,169	6.6	528	2.6	29,641	6.8	1852	32.8
10	Cast-iron unlined	23,404	5.1	42	0.2	23,362	5.4	1852	32.5
12		22,017	4.8	42	0.2	21,975	5.1	1885	25.8
16		3,329	0.7	0	0.0	3,329	0.7	1885	46.7
20		4,246	0.9	0	0.0	4,246	1.0	1885	51.1
2		27,392	6.0	3,032	14.7	24,360	5.6	1930	6.3
6	Cast-iron cement-lined	63,096	13.9	0	0.0	63,096	14.5	1930	3.7
8		18,693	4.1	0	0.0	18,693	4.3	1930	3.1
12		2,061	0.5	0	0.0	2,061	0.5	1931	2.8
¾		349	0.1	0	0.0	349	0.1	1923	16.8
1		266	0.1	0	0.0	266	0.1	1924	16.5
1¼		1,280	0.3	473	2.3	807	0.2	1923	16.7
2	Galvanized steel	12,248	2.7	1,363	6.6	10,885	2.5	1918	15.8
2½		1,373	0.3	258	1.3	1,115	0.3	1921	14.5
3		1,649	0.4	0	0.0	1,649	0.4	1924	14.2
4		4,249	0.9	2,676	13.0	1,573	0.4	1913	16.5
1½		3,131	0.7	1,850	9.0	1,281	0.3	1852	15.9
2	Galvanized wrought-iron	9,366	2.1	6,613	32.2	2,753	0.6	1852	15.5
2½		600	0.1	600	2.9	0	0.0	1866	
3		1,643	0.4	0	0.0	1,643	0.4	1925	15.5
1	Lead	16	0.0	0	0.0	16	0.0	1923	17.5
1½	Lead	18	0.0	0	0.0	18	0.0	1926	14.5
TOTAL		454,223	100.0	20,560	100.0	433,663	100.0		27.0
Percentage of Total		100.00		4.53		95.47			
Average size, in.		5.97		2.87		6.12			

Mortality Survival Ratios

Size, in.	Kind	No. of Feet	Period Covered, yr.	Percentage
¾–1½	All	5,060	40.5	0
2–4	Galvanized wrought-iron and galvanized steel	31,128	31.5	0
4		97,978	88.5	97.991
6		125,650	88.5	88.818
8	Cast-iron unlined	30,169	88.5	95.324
10–12		45,421	88.5	99.068
Over 12		7,575	55.5	100.000
2	Cast-iron cement-lined	27,392	10.5	82.734
6–12	Cast-iron cement-lined	83,850	10.5	100.000
TOTAL		454,223		

* Unindentified Pipe: 74 ft. of 4-in. cast-iron unlined; 201 ft. of 6-in. cast-iron unlined.

in sufficient quantity and head to furnish not only the water supply but to provide power to drive an overshot water wheel. A 1-mgd. reciprocating pump, actuated by the water wheel, elevated the water to the storage basin from which it flowed by gravity to the distribution system.

The original pumping station building, which was constructed of limestone, and the raceway were originally part of a mill property constructed many years before. The race still continues in service and the major part of the original building is incorporated in the existing pumping station.

In 1855 a steam engine and boiler were installed in the pumping station, affording an alternate source of power for pumping. The original pump has also continued in service until the present time.

In 1874 and 1875 a second storage basin, with a capacity of about 13.5 mil.gal., was built adjacent to the original basin. These basins are located on a hill about 1 mi. west of the center of Old Alexandria at an elevation of about 100 ft.

The supply as it existed in 1875 sufficed until 1913 when increased demands for water necessitated the construction of an impounding dam on the upper waters of Holmes Run. This dam, known as the Barcroft Dam, is
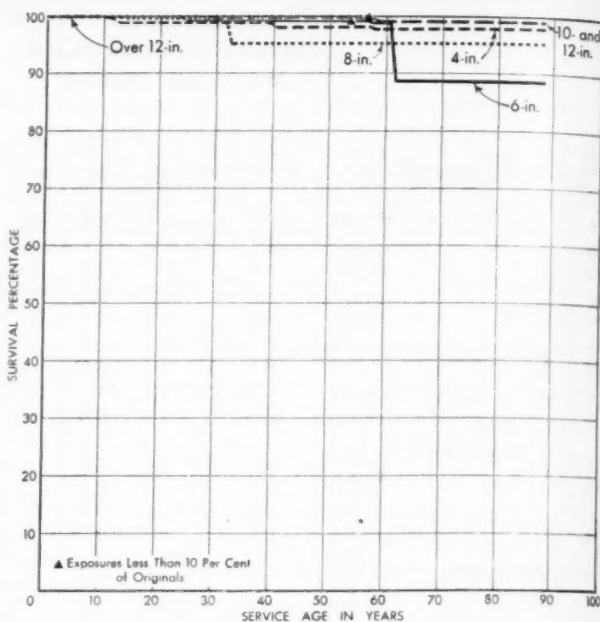
FIG. 1. Mortality Survival Curve—4–20-in. Cast-Iron Unlined Mains—Alexandria, Virginia

BASE: Feet		SURVIVAL: 1852–1940	
SIZE *in.*		EXPOSURES *ft.*	RETIREMENTS *ft.*
4		97,978	1,425
6		125,650	1,658
8		30,169	528
10 and 12		45,421	84
Over 12		7,575	0

a stone and concrete masonry dam, 500 ft. long, with a spillway section 160 ft. long. It is of gravity type construction with a spillway elevation of 205 ft. and a capacity of 600 mil.gal.

The total area of the watershed above the dam is about 14 sq.mi. and the combined area of the sheds on Holmes Run and Back Lick Run above the point of diversion is 33 sq.mi. As presently developed they have an estimated total safe yield of about 7 mgd. The impounded storage is released through control gates into Holmes Run as required. The manner in which the
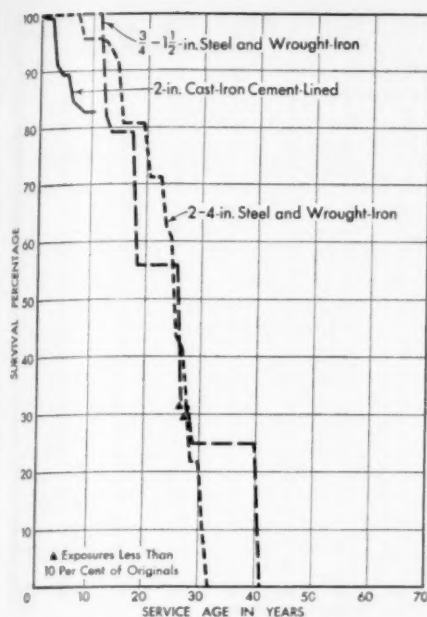
FIG. 2. Mortality Survival Curve—¾–4-in. Mains—Alexandria, Virginia

BASE: Feet		SURVIVAL: 1852–1940	
		EXPO-	RETIRE-
SIZE in.	KIND	SURES ft.	MENTS ft.
¾–1½	Wrought-Iron and Steel	5,060	2,323
2–4	Wrought-Iron and Steel	31,128	11,510
2	Cast-Iron Cement Lined	27,392	3,032

water is brought to the pump station from the diversion dam through the race is the same now as it was in 1852.

In 1918 a 2.5-mgd. filtration plant was built. It went into service in 1919. It is located adjacent to the storage basins and the original construction consisted of two cypress sedimentation tanks and five New York Continental rapid sand filters.

The elevation of the storage basins was planned to supply the original town of Alexandria, which has an elevation of about 50 ft., by gravity. As the system extended to take in contiguous

territory, three separate high-service areas supplied by booster pumps were developed so that the elevations now served range from sea level to 275 ft. above.

In 1933 it became necessary to increase pressures throughout the original system. This was accomplished by discontinuing gravity feed and returning the water from the basins to the pump station where high-service pumps were installed which delivered the water at greater pressure to the distribution system.

The original filter plant consisted of five 0.5-mgd. units. An additional unit was added in 1929 and two more units in 1937. Also at this time the original filter house, which was of wood construction, was replaced with a brick structure.

Basis of Study

The data on pipe and valves were compiled from a study made for the purpose of listing all pipe and valves that had been retired over the life of the property. The study was made coincidently with an inventory of existing mains. Company records pertaining to size, kind and date of installation were fairly complete over the entire plant life. Existing retirement records were checked and supplemented by a comparison of pipe and valves installed with the present existence by specific locations.

The record on valves has not been carried forward beyond the date of the original study. This record is through Dec. 31, 1930.

Mortality Survival Study

Mortality studies were made of mains and valves. Table 1 is a summary of the pipe installed, the amount retired and that still in service, as well as other pertinent data. Figures 1 and

2 show the mortality survival curves covering the amount and classification of pipe grouped as shown.

Table 2 and Figure 3 represent a similar study of valves.

A brief summary of Class B facilities covering the major items is given below.

Causes of Retirement

There exists no complete record from which could be determined the causes of retirement of mains and valves.

Acknowledgments

The collection and compilation of data pertaining to the Alexandria Water Company were carried out by the personnel of the American Water Works and Electric Company, Inc.
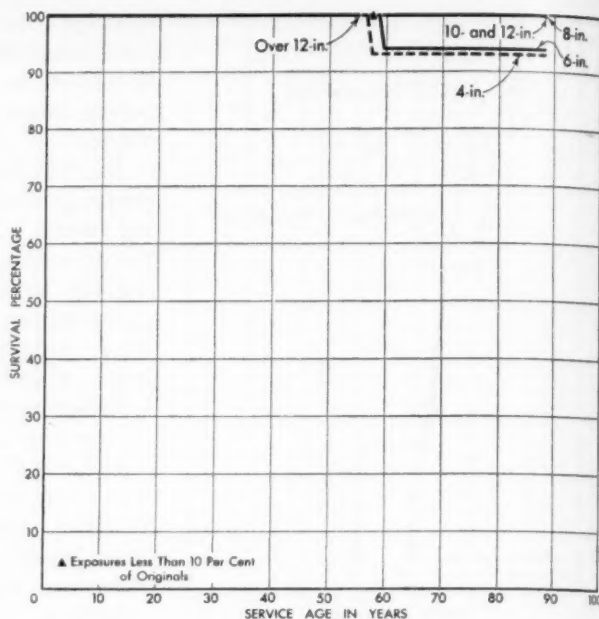
Fig. 3. Mortality Survival Curve—4–20-in. Gate Valves—Alexandria, Virginia

BASE: Unit		SURVIVAL: 1852–1940
SIZE *in.*	EXPOSURES *Units*	RETIREMENTS *Units*
4	156	2
6	182	1
8	49	0
10 and 12	54	0
Over 12	8	0

SUMMARY OF CLASS B FACILITIES
ALEXANDRIA, VIRGINIA

Impounding Reservoirs

Barcroft Reservoir—On Holmes Run, concrete masonry dam, 500 ft. long, maximum height 68 ft., capacity 617 mil.gal. Constructed in 1915 and still in service.

Aqueducts

Cameron Raceway—From diversion dam to pumping station, 9,000 ft. long, 12 to 15 ft. wide, 3 ft. deep. Originally constructed in 1800, straightened in 1866, 1,250 ft. relocated in 1875 and still in service.

Taylors Run Aqueduct—Section of above raceway over Taylors Run, concrete filled brick arches on steel I beams; 40 ft. long, 20 ft.

wide and 8 ft. high. Built in 1893 and still in service.

Purification Plant

Two wood sedimentation tanks, 44 ft. in diameter by 16 ft. high. Three wood coagulating tanks, 5 ft. in diameter by 5 ft. high. Six wood filter units, 15 ft. in diameter by 8 ft. high. Chemical feed equipment. Constructed in 1918 and still in service.

Pumping Equipment

No. 1—Reciprocating pump, driven by water wheel, capacity 1 mgd. at 81-ft. head. Installed in 1851, original water wheel replaced in 1902, pump and water wheel still in service.

TABLE 2

SUMMARY OF VALVES

ALEXANDRIA, VIRGINIA

Size. in.	Number Installed	Number Identified	Number Retired	Number in Service	Year of First Installation	Average Age. yr.
1	4	4	0	4	1926	4.5
2	50	25	0	25	1912	5.5
2½	1	1	0	1	1926	4.5
3	5	5	0	5	1925	27.5
4	224	156	2	154	1852	35.4
6	314	182	1	181	1852	22.4
8	58	49	0	49	1852	24.8
10	41	36	0	36	1852	18.0
12	26	18	0	18	1885	20.8
16	6	5	0	5	1885	40.7
20	3	3	0	3	1885	38.5
TOTAL	732	484	3	481		25.5
Percentage of Total		100.00	0.62	99.38		

Mortality Survival Ratios

Size, in.	Number	Period Covered, yr.	Percentage
1–3	35	28.5	100.000
4	156	88.5	93.333
6	182	88.5	94.118
8	49	88.5	100.000
10 and 12	54	88.5	100.000
Over 12	8	55.5	100.000
TOTAL	484		

SUMMARY OF CLASS B FACILITIES (contd.)

Pumping Equipment (contd.)

No. 2—Steam engine-driven pump, capacity 1.5 mgd. at 81-ft. head. Installed in 1898 and still in service.

No. 3—Steam turbine-driven centrifugal pump, capacity 3 mgd. at 110-ft. head. Installed in 1928 and still in service.

No. 4—Water turbine-driven centrifugal pump, capacity 1.3 mgd. at 105-ft. head. Installed in 1928, replaced in 1937 by diesel unit. Pump in stock, turbine $100 salvage.

No. 5—Motor-driven centrifugal pump, capacity 0.3 mgd. at 192-ft. head, 20-hp. motor. Installed in 1928 and still in service.

No. 6—Motor-driven centrifugal pump, capacity 0.3 mgd. at 253-ft. head, 30-hp.

motor. Installed in 1929 and still in service.

No. 7—Motor-driven centrifugal pump, capacity 0.14 mgd. at 268-ft. head, 15-hp. motor. Installed in 1927 and still in service.

No. 8—Motor-driven centrifugal pump, capacity 0.14 mgd. at 130-ft. head, 7.5-hp. motor. Installed in 1927 and still in service.

Wash Water Pump—Motor-driven centrifugal pump, capacity 0.5 mgd. at 55-ft. head, 10-hp. motor. Installed in 1918 and still in service.

Seminary Station—Motor-driven triplex pump, 7.5-hp. motor. Installed in 1928 and still in service.

Belle Haven Station—Small vertical deep well pump, 3-hp. motor. Installed in 1927 and still in service.

SUMMARY OF CLASS B FACILITIES (contd.)

Distribution Reservoirs

No. 1 Reservoir—Open, excavated, brick lined, 182-ft. square reservoir; capacity 2.5 mil. gal., 17 ft. deep. Constructed in 1852 and still in service.

No. 2 Reservoir—Open, excavated, stone-paved reservoir; capacity 14 mil.gal., 337 ft. wide by 500 ft. long, 17 ft. deep. Constructed in 1875 and still in service.

St. Elmo Reservoir—Covered reinforced concrete reservoir; capacity 0.7 mil.gal., 70.67 ft. wide by 94.67 ft. long, 16.5 ft. deep. Constructed in 1927 and still in service.

Tanks and Standpipes

Jefferson Park Standpipe—Covered steel standpipe, capacity 705,000 gal., 40 ft. in diameter by 75 ft. high. Erected in 1928 and still in service.

Seminary Elevated Tank—Covered steel elevated tank, capacity 50,000 gal., 18 ft. in diameter by 20 ft. deep, 50 ft. to flow line. Erected in 1913 and still in service.

Belle Haven Elevated Tank—Covered wood tank, capacity 20,000 gal.; 16 ft. in diameter by 13.33 ft. deep, 50 ft. to flow line. Erected in 1927 and still in service.

SUMMARY OF INSTALLATIONS AND RETIREMENTS
ALEXANDRIA, VIRGINIA

MAINS

4-IN. CAST-IRON UNLINED MAINS

Year Installed	Installed (Feet)	In Service (Feet)	Retired (Feet)	Year Installed	Installed (Feet)	In Service (Feet)	Retired (Feet)
1852	14,032	13,996	36	1902	147	147	0
1853	933	933	0	1903	542	542	0
1856	307	307	0	1904	1,856	1,856	0
1858	627	627	0	1905	1,374	1,374	0
1869	323	323	0	1907	2,027	2,027	0
1870	602	591	11	1908	11,555	11,555	0
1871	1,260	1,260	0	1909	2,516	2,516	0
1875	387	387	0	1910	10,880	10,880	0
1878	409	409	0	1911	2,410	2,410	0
1879	865	865	0	1912	2,451	2,451	0
1880	1,508	1,508	0	1913	2,892	2,892	0
1881	316	316	0	1914	309	309	0
1882	420	420	0	1916	378	378	0
1884	2,814	2,814	0	1918	202	202	0
1885	2,570	2,570	0	1919	29	29	0
1886	309	309	0	1920	20	20	0
1887	330	330	0	1921	283	283	0
1888	2,564	2,540	24	1923	192	192	0
1889	1,149	1,149	0	1925	11	11	0
1891	2,842	2,842	0	1926	468	468	0
1892	932	932	0	1927	6	6	0
1893	1,863	1,863	0	1928	209	209	0
1894	6,120	6,120	0	1929	203	203	0
1895	1,390	766	624	1940	0	0	0
1896	1,420	1,206	214				
1897	1,941	1,941	0	SUBTOTAL	97,978	96,553	1,425
1898	2,226	2,226	0	Unknown	74	0	74
1899	3,550	3,034	516				
1900	420	420	0	TOTAL	98,052	96,553	1,499
1901	2,589	2,589	0				

Retirements by Years

Year Installed	Feet	Year	Year Installed	Feet	Year
1852	36	1909	1895	624	1907
1870	11	1897	1896	214	1907
1888	24	1911	1899	516	1939

6-IN. CAST-IRON UNLINED MAINS

Year Installed	Installed (Feet)	In Service (Feet)	Retired (Feet)	Year Installed	Installed (Feet)	In Service (Feet)	Retired (Feet)
1852	10,702	9,454	1,248	1888	1,701	1,701	0
1853	313	313	0	1890	410	0	410
1877	420	420	0	1892	2,851	2,851	0
1878	409	409	0	1893	774	774	0
1885	244	244	0	1896	875	875	0
1886	423	423	0	1897	3,695	3,695	0

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wood
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6-IN. CAST-IRON UNLINED MAINS (contd.)

Year Installed	Installed	In Service	Retired	Year Installed	Installed	In Service	Retired
1898	1,811	1,811	0	1922	4,191	4,191	0
1899	711	711	0	1923	6,249	6,249	0
1902	377	377	0	1924	6,189	6,189	0
1903	2,314	2,314	0	1925	3,587	3,587	0
1904	753	753	0	1926	9,694	9,694	0
1905	434	434	0	1927	11,930	11,930	0
1906	1,530	1,530	0	1928	10,740	10,740	0
1907	2,062	2,062	0	1929	4,434	4,434	0
1908	5,309	5,309	0	1940	0	0	0
1909	2,008	2,008	0				
1910	5,067	5,067	0	SUBTOTAL	125,650	123,992	1,658
1911	726	726	0	Unknown	201	0	201
1913	2,217	2,217	0				
1914	2,778	2,778	0	TOTAL	125,851	123,992	1,859
1915	2,949	2,949	0				
1916	3,090	3,090	0				
1918	5,516	5,516	0				
1919	2,858	2,858	0				
1920	1,870	1,870	0				
1921	1,439	1,439	0				

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1852	24	1909	1,224	1913
1890	410	1914		

8-IN. CAST-IRON UNLINED MAINS

Year Installed	Installed	In Service	Retired	Year Installed	Installed	In Service	Retired
1852	4,776	4,776	0	1926	4,750	4,750	0
1870	1,317	867	450	1927	9,580	9,580	0
1872	54	0	54	1928	262	262	0
1897	1,244	1,244	0	1940	0	0	0
1898	1,961	1,937	24				
1902	450	450	0	TOTAL	30,169	29,641	528
1905	417	417	0				
1907	24	24	0				
1916	1,876	1,876	0				
1918	978	978	0				
1919	394	394	0				
1920	882	882	0				
1921	38	38	0				
1922	1,166	1,166	0				

Retirements by Years

Year Installed	Feet	Year
1870	450	1902
1872	54	1885
1898	24	1907

10-IN. CAST-IRON UNLINED MAINS

Year Installed	Installed	In Service	Retired	Year Installed	Feet	Year
1852	3,908	3,884	24	1852	24	1910
1885	3,450	3,432	18	1885	18	1914
1905	938	938	0			
1927	3,969	3,969	0			
1928	11,139	11,139	0			
1940	0	0	0			
TOTAL	23,404	23,362	42			

The right portion of the 10-in. table is headed *Retirements by Years*.

12-IN. CAST-IRON UNLINED MAINS

Retired	Year Installed	Installed (Feet)	In Service (Feet)	Retired
0	1885	1,719	1,677	42
0	1897	1,900	1,900	0
0	1906	1,425	1,425	0
0	1908	916	916	0
0	1911	4,523	4,523	0
0	1920	414	414	0
0	1922	1,749	1,749	0
0	1923	3,614	3,614	0
0	1926	568	568	0
	1927	2,424	2,424	0
1,658	1928	2,765	2,765	0
201	1940	0	0	0
1,859	TOTAL	22,017	21,975	42

Retirements by Years

Year	Year Installed	Feet	Year
1913	1885	42	1914

16-IN. CAST-IRON UNLINED MAINS

Retired	Year Installed	Installed (Feet)	In Service (Feet)	Retired
0	1885	1,443	1,443	0
0	1897	1,675	1,675	0
0	1928	211	211	0
0	1940	0	0	0
528	TOTAL	3,329	3,329	0

20-IN. CAST-IRON UNLINED MAINS

Year Installed	Installed (Feet)	In Service (Feet)	Retired
1885	3,308	3,308	0
1905	938	938	0
1940	0	0	0
TOTAL	4,246	4,246	0

2-IN. CAST-IRON CEMENT-LINED MAINS

Year Installed	Installed (Feet)	In Service (Feet)	Retired
1930	8,327	7,412	915
1931	2,272	2,151	121
1932	833	559	274
1933	3,299	1,607	1,692
1934	1,409	1,409	0

2-IN. CAST-IRON CEMENT-LINED MAINS (contd.)

Year Installed	Installed (Feet)	In Service (Feet)	Retired
1935	1,645	1,615	30
1936	791	791	0
1937	703	703	0
1938	3,392	3,392	0
1939	3,200	3,200	0
1940	1,521	1,521	0
TOTAL	27,392	24,360	3,032

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1930	781	1936	134	1938
1931	121	1938		
1932	274	1936		
1933	1,692	1936		
1935	30	1936		

6-IN. CAST-IRON CEMENT-LINED MAINS

Year Installed	Installed (Feet)	In Service (Feet)	Retired
1930	3,305	3,305	0
1931	3,041	3,041	0
1933	292	292	0
1934	84	84	0
1935	8,120	8,120	0
1936	12,249	12,249	0
1937	7,897	7,897	0
1938	8,978	8,978	0
1939	8,224	8,224	0
1940	10,906	10,906	0
TOTAL	63,096	63,096	0

8-IN. CAST-IRON CEMENT-LINED MAINS

Year Installed	Installed (Feet)	In Service (Feet)	Retired
1930	789	789	0
1931	348	348	0
1933	36	36	0
1935	132	132	0
1936	6,085	6,085	0
1937	2,113	2,113	0
1938	1,373	1,373	0
1939	3,160	3,160	0
1940	4,657	4,657	0
TOTAL	18,693	18,693	0

12-IN. CAST-IRON CEMENT-LINED MAINS

Year	Feet		
Installed	Installed	In Service	Retired
1931	50	50	0
1937	1,405	1,405	0
1939	41	41	0
1940	559	559	0
TOTAL	2,061	2,061	0

¾-IN. GALVANIZED STEEL MAINS

Year	Feet		
Installed	Installed	In Service	Retired
1923	88	88	0
1924	261	261	0
1940	0	0	0
TOTAL	349	349	0

1-IN. GALVANIZED STEEL MAINS

Year	Feet		
Installed	Installed	In Service	Retired
1924	266	266	0
1940	0	0	0
TOTAL	266	266	0

1¼-IN. GALVANIZED STEEL MAINS

Year	Feet		
Installed	Installed	In Service	Retired
1923	153	153	0
1924	1,127	654	473
TOTAL	1,280	807	473

Retirements by Years

Year Installed	Feet	Year
1924	473	1936

2-IN. GALVANIZED STEEL MAINS

Year	Feet		
Installed	Installed	In Service	Retired
1918	276	276	0
1919	173	173	0
1922	821	821	0
1924	4,717	4,717	0
1925	385	385	0
1926	2,938	2,938	0
1927	810	810	0

2-IN. GALVANIZED STEEL MAINS (contd.)

Year	Feet		
Installed	Installed	In Service	Retired
1928	765	765	0
1929	1,363	0	1,363
1940	0	0	0
TOTAL	12,248	10,885	1,363

Retirements by Years

Year Installed	Feet	Year
1929	1,363	1936

2½-IN. GALVANIZED STEEL MAINS

Year	Feet		
Installed	Installed	In Service	Retired
1921	258	0	258
1926	1,115	1,115	0
1940	0	0	0
TOTAL	1,373	1,115	258

Retirements by Years

Year Installed	Feet	Year
1921	258	1935

3-IN. GALVANIZED STEEL MAINS

Year	Feet		
Installed	Installed	In Service	Retired
1924	508	508	0
1927	952	952	0
1929	189	189	0
1940	0	0	0
TOTAL	1,649	1,649	0

4-IN. GALVANIZED STEEL MAINS

Year	Feet		
Installed	Installed	In Service	Retired
1913	1,222	0	1,222
1924	3,027	1,573	1,454
1940	0	0	0
TOTAL	4,249	1,573	2,676

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1913	1,222	1928		
1924	145	1936	1,309	1939

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ntd.)

Retired
0
1,363
0
—
1,363

s

Retired
258
0
0
—
258

s

Retired
0
0
0
0
—
0

s

Retired
1,222
1,454
0
—
2,676

Year

1939

1-IN. LEAD MAINS

Year Installed	Installed	In Service	Retired
1923	16	16	0
1940	0	0	0
	—	—	—
TOTAL	16	16	0

(Feet)

1½-IN. LEAD MAINS

Year Installed	Installed	In Service	Retired
1926	18	18	0
1940	0	0	0
	—	—	—
TOTAL	18	18	0

(Feet)

1½-IN. GALVANIZED WROUGHT-IRON MAINS

Year Installed	Installed	In Service	Retired
1852	100	0	100
1853	400	0	400
1859	1,200	0	1,200
1924	890	740	150
1925	445	445	0
1927	96	96	0
1940	0	0	0
TOTAL	3,131	1,281	1,850

(Feet)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1852	100	1880				
1853	400	1893				
1859	425	1871	375	1877	400	1885
1924	150	1937				

2-IN. GALVANIZED WROUGHT-IRON MAINS

Year Installed	Installed	In Service	Retired
1852	650	0	650
1853	725	0	725
1860	2,150	0	2,150
1866	444	0	444
1867	1,522	0	1,522

(Feet)

2-IN. GALVANIZED WROUGHT-IRON MAINS (contd.)

Year Installed	Installed	In Service	Retired
1868	768	0	768
1869	243	0	243
1871	111	0	111
1925	2,753	2,753	0
1940	0	0	0
TOTAL	9,366	2,753	6,613

(Feet)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1852	650	1875				
1853	725	1884				
1860	1,200	1885	950	1890		
1866	198	1880	246	1893		
1867	450	1880	186	1893	436	1894
	450	1895				
1868	207	1882	205	1888	158	1892
	198	1896				
1869	243	1896				
1871	111	1896				

2½-IN. GALVANIZED WROUGHT-IRON MAINS

Year Installed	Installed	In Service	Retired
1866	600	0	600
1940	0	0	0
	—	—	—
TOTAL	600	0	600

(Feet)

Retirements by Years

Year Installed	Feet	Year
1866	600	1886

3-IN. GALVANIZED WROUGHT-IRON MAINS

Year Installed	Installed	In Service	Retired
1925	1,643	1,643	0
1940	0	0	0
	—	—	—
TOTAL	1,643	1,643	0

(Feet)

VALVES

1-IN. VALVES

Year	Number		
Installed	Installed	In Service	Retired
1926	4	4	0
1930	0	0	0
	—	—	—
TOTAL	4	4	0

2-IN. VALVES

Year	Number		
Installed	Installed	In Service	Retired
1912	1	1	0
1918	1	1	0
1925	13	13	0
1926	3	3	0
1927	5	5	0
1928	2	2	0
1930	0	0	0
	—	—	—
SUBTOTAL	25	25	0
Unknown	25	25	0
	—	—	—
TOTAL	50	50	0

2½-IN. VALVES

Year	Number		
Installed	Installed	In Service	Retired
1926	1	1	0
1930	0	0	0
	—	—	—
TOTAL	1	1	0

3-IN. VALVES

Year	Number		
Installed	Installed	In Service	Retired
1925	5	5	0
1930	0	0	0
	—	—	—
TOTAL	5	5	0

4-IN. VALVES

Year	Number		
Installed	Installed	In Service	Retired
1852	20	18	2
1869	1	1	0
1870	1	1	0
1871	1	1	0

4-IN. VALVES (contd.)

Year	Number		
Installed	Installed	In Service	Retired
1875	1	1	0
1878	2	2	0
1880	3	3	0
1881	1	1	0
1884	2	2	0
1885	2	2	0
1886	1	1	0
1887	2	2	0
1888	3	3	0
1889	3	3	0
1891	3	3	0
1892	1	1	0
1893	4	4	0
1894	6	6	0
1895	3	3	0
1896	2	2	0
1897	9	9	0
1898	7	7	0
1899	12	12	0
1900	1	1	0
1901	1	1	0
1902	1	1	0
1903	1	1	0
1904	1	1	0
1905	3	3	0
1906	2	2	0
1907	14	14	0
1908	12	12	0
1909	2	2	0
1910	2	2	0
1911	6	6	0
1912	3	3	0
1913	6	6	0
1914	2	2	0
1917	1	1	0
1918	2	2	0
1920	1	1	0
1926	2	2	0
1927	1	1	0
1930	2	2	0
	—	—	—
SUBTOTAL	156	154	2
Unknown	68	68	0
	—	—	—
TOTAL	224	222	2

Retirements by Years

Year Installed	Number	Year
1852	2	1910

6-IN. VALVES

Year Installed	Number Installed	In Service	Retired
1852	14	13	1
1876	1	1	0
1878	1	1	0
1879	1	1	0
1882	1	1	0
1885	1	1	0
1886	2	2	0
1888	3	3	0
1892	4	4	0
1893	1	1	0
1896	2	2	0
1897	21	21	0
1898	4	4	0
1899	2	2	0
1902	1	1	0
1903	6	6	0
1904	3	3	0
1905	1	1	0
1906	3	3	0
1907	4	4	0
1908	5	5	0
1910	2	2	0
1911	1	1	0
1912	1	1	0
1913	6	6	0
1914	9	9	0
1915	8	8	0
1916	5	5	0
1917	1	1	0
1918	5	5	0
1920	1	1	0
1921	3	3	0
1923	1	1	0
1926	6	6	0
1927	23	23	0
1928	21	21	0
1929	6	6	0
1930	2	2	0
SUBTOTAL	182	181	1
Unknown	132	132	0
TOTAL	314	313	1

Retirements by Years

Year Installed	Number	Year
1852	1	1911

8-IN. VALVES

Year Installed	Number Installed	In Service	Retired
1852	8	8	0
1870	2	2	0
1897	2	2	0
1898	5	5	0
1905	1	1	0
1906	1	1	0
1912	1	1	0
1916	4	4	0
1919	2	2	0
1926	5	5	0
1927	18	18	0
1930	0	0	0
SUBTOTAL	49	49	0
Unknown	9	9	0
TOTAL	58	58	0

10-IN. VALVES

Year Installed	Number Installed	In Service	Retired
1852	3	3	0
1885	7	7	0
1906	1	1	0
1927	8	8	0
1928	17	17	0
1930	0	0	0
SUBTOTAL	36	36	0
Unknown	5	5	0
TOTAL	41	41	0

12-IN. VALVES

Year Installed	Number Installed	In Service	Retired
1885	3	3	0
1897	3	3	0
1906	2	2	0
1908	1	1	0
1911	2	2	0
1923	1	1	0
1926	1	1	0
1927	2	2	0
1928	3	3	0

12-IN. VALVES (contd.)

Year	Number		
Installed	Installed	In Service	Retired
1930	0	0	0
	—	—	—
SUBTOTAL	18	18	0
Unknown	8	8	0
	—	—	—
TOTAL	26	26	0

16-IN. VALVES

Year	Number		
Installed	Installed	In Service	Retired
1885	3	3	0
1897	2	2	0
1930	0	0	0
	—	—	—

16-IN. VALVES (contd.)

Year	Number		
Installed	Installed	In Service	Retired
SUBTOTAL	5	5	0
Unknown	1	1	0
	—	—	—
TOTAL	6	6	0

20-IN. VALVES

Year	Number		
Installed	Installed	In Service	Retired
1885	2	2	0
1906	1	1	0
1930	0	0	0
	—	—	—
TOTAL	3	3	0

Winnipeg, Manitoba—Survival and Retirement Experience With Water Works Facilities

As of December 31, 1942

THE Greater Winnipeg Water District represents the group of municipalities centered in the city of Winnipeg, located in the south central part of the Province of Manitoba. It was formed through incorporation by the legislature and is managed by a commission under the jurisdiction of an administration board composed of representatives from the municipalities concerned. These communities include the cities of Winnipeg and St. Boniface; the municipalities of St. James, Tuxedo, Fort Garry, St. Vital, East and West Kildonan; and the town of Transcona. The aggregate population of this area is approximately 260,000.

This report is confined to studies of distribution facilities owned and operated by the city of Winnipeg. Besides being the capital of Manitoba, Winnipeg, the fourth largest Canadian city, is the urban center of central Canada and is the retail, wholesale and trading center of the area. It is also a railroad center and has important manufacturing establishments represented in woodworking, clothing, iron, farm implements and packing plants. The city is located on level terrain at the confluence of the Red and Assiniboine rivers.

At the date of the study there were 40,471 consumers receiving service within the city. Water purchased by the city from the district and used within its service area averaged 16.4 mgd. (Imperial gallons are used throughout), serving 227,000 people, or about 72.3 gpd. per capita.

Development of the Existing System

The original water facilities serving Winnipeg secured their supply from the Assiniboine River. These works were constructed by a private company and so operated from about 1882 to 1899 when they were purchased by the city. The city in 1912 joined with the surrounding municipalities in promoting the formation of the Greater Winnipeg Water District, which developed the existing supply and furnishes water in bulk to the several communities by meter measurement.

About the time of the purchase of the privately-operated works the development of a well supply was started and from 1901 to the commencement of operation of the district supply system in 1919 the entire supply for the city was obtained from wells.

The present supply is secured from Shoal Lake located about 95 mi. east of the city and flows by gravity through a concrete aqueduct to the city. The district supplies water in bulk, under low pressure, from the aqueduct to the city of Winnipeg, which, upon receipt of the water at the reservoirs, assumes control of its storage, treatment, pumping and distribution, the latter functions being carried out under the direction of the city engineer. The city in turn provides treated water under serv-

TABLE 1

SUMMARY OF MAINS
WINNIPEG, MANITOBA

Size, in.	Kind	No. of Feet Installed	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, yr.
3		199	0.01	0	0	199	0.01	1942	0.5
4		195,136	10.93	58,955	48.89	136,181	8.18	1882	40.9
5		14,775	0.83	9,005	7.47	5,770	0.35	1883	54.4
6		951,972	53.30	26,475	21.96	925,497	55.58	1882	32.7
8		244,035	13.66	20,856	17.29	223,179	13.40	1882	27.7
10	Cast-iron	164,306	9.19	532	0.44	163,774	9.84	1882	31.4
12	unlined	94,684	5.30	3,458	2.87	91,226	5.48	1882	28.5
14		40,268	2.25	45	0.04	40,223	2.42	1889	33.6
16		18,868	1.06	0	0	18,868	1.13	1899	36.9
18		39,750	2.26	1,113	0.92	38,637	2.32	1899	26.5
20		4,200	0.23	148	0.12	4,052	0.24	1899	41.6
24		11	0.00	0	0	11	0.00	1919	23.5
10	Cast-iron flexible joint unlined	839	0.05	0	0	839	0.05	1904	36.0
12		782	0.04	0	0	782	0.05	1925	17.5
18	Cast-iron victaulic unlined	113	0.01	0	0	113	0.01	1939	3.5
6		571	0.02	0	0	571	0.03	1940	2.5
10	Asbestos-	8,854	0.50	0	0	8,854	0.53	1937	4.0
14	cement	431	0.02	0	0	431	0.03	1932	10.5
18		859	0.05	0	0	859	0.05	1932	9.6
24	Concrete	3,899	0.22	0	0	3,899	0.23	1938	4.5
36	Steel, concrete covered	1,200	0.07	0	0	1,200	0.07	1919	23.5
TOTAL		1,785,752	100.00	120,587	100.00	1,665,165	100.00		32.3
Percentage of Total		100.00		6.75		93.25			
Average Size, in.		7.44		5.61		7.54			

Mortality Survival Ratios

Size, in.	Kind	No. of Feet	Period Covered, yr.	Percentage
3–5		210,110	60.5	36.572
6		951,972	60.5	68.606
8	Cast-iron unlined	244,035	60.5	17.914
10–12		258,990	60.5	97.800
Over 12		103,097	53.5	97.997
6–18	Asbestos-cement	10,715	10.5	100.000
10–18	Cast-iron flexible and victaulic	1,734	38.5	100.000
24	Concrete	3,899	4.5	100.000
36	Steel, concrete covered	1,200	23.5	100.000
TOTAL		1,785,752		
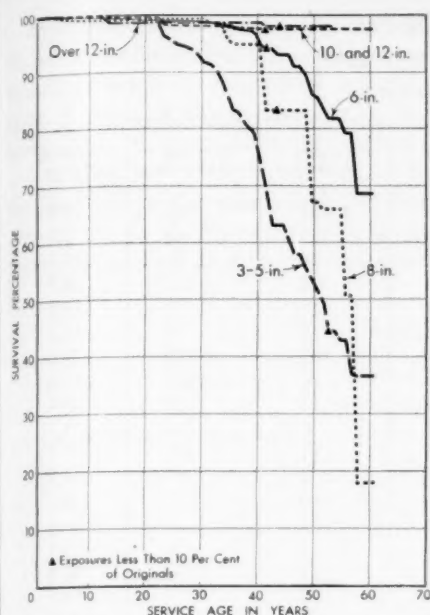
Fig. 1. Mortality Survival Curve—3–24-in. Cast-Iron Unlined Mains— Winnipeg, Manitoba

BASE: Feet   SURVIVAL: 1882–1942

SIZE in.	EXPOSURES ft.	RETIREMENTS ft.
3–5	210,110	67,960
6	951,972	26,475
8	244,035	20,856
10 and 12	258,990	3,990
Over 12	103,097	1,306
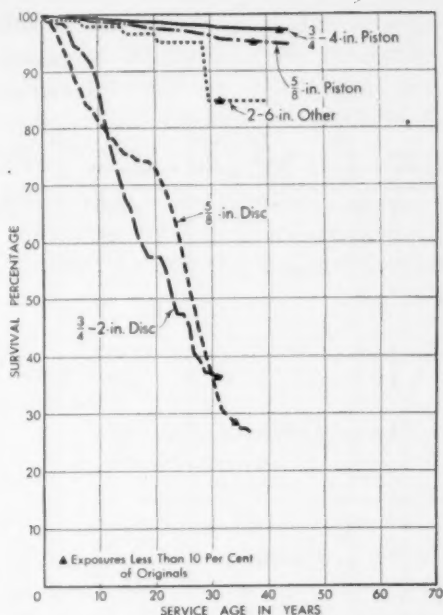
FIG. 2. Mortality Survival Curve—⅛–6-in. Meters—Winnipeg, Manitoba

BASE: Unit   SURVIVAL: 1899–1942

SIZE in.	KIND	EXPOSURES Units	RETIREMENTS Units
⅝	Disc	2,056	1,132
⅝	Piston	37,646	1,401
¾–3	Disc	262	92
¾–4	Piston	2,955	58
2–6	Other	112	7

ice pressures to the municipalities of East Kildonan, West Kildonan, Fort Garry, St. James, Charleswood, the town of Tuxedo, and the village of Brooklands.   Water in bulk is also supplied by the district, through independent connections to the aqueduct, to the city of St. Boniface and the town of Transcona, which also store, treat, pump and distribute the water to the citizens resident in these municipalities. St. Boniface in turn provides water under service pressure to the municipality of St. Vital.

The Shoal Lake supply was first considered in 1912 but preliminary work over the several following years, including the building of a standard gage railroad along the line of the aqueduct, was required before actual construction could be started in 1915. Water was turned into the system in April 1919.

Shoal Lake is an arm of the Lake of the Woods, the geography of which is international and is situated about 95 mi. east of and 300 ft. in elevation above the city.   Shoal Lake has a drainage area of about 360 sq.mi., with

TABLE 2

SUMMARY OF METERS
WINNIPEG, MANITOBA

Size, in.	Kind	Number Installed	Number Identified	Number Retired	Number in Service	Average Age, yr.
5/8	Disc	2,099	2,056	1,132	924	17.4
3/4		54	51	9	42	1.5
1		136	117	35	82	15.5
1½		54	30	8	22	8.7
2		59	56	35	21	13.6
3		9	8	5	3	22.2
5/8	Piston	37,937	37,646	1,401	36,245	29.0
3/4		1,695	1,662	27	1,635	33.8
1		756	743	13	730	30.9
1½		322	322	6	316	24.7
2		215	214	11	203	25.5
3		13	12	1	11	32.9
4		2	2	0	2	30.5
2	Current	4	4	4	0	—
3		19	18	2	16	32.1
4		8	7	1	6	26.8
6		1	1	0	1	16.5
3	Compound	55	55	0	55	17.0
4		23	23	0	23	16.2
6		4	4	0	4	15.8
TOTAL		43,465	43,031	2,690	40,341	28.8
Percentage of Total			100.0	6.25	93.75	

Mortality Survival Ratios

Size, in.	Kind	Number	Period Covered, yr.	Percentage
5/8	Disc	2,056	36.5	26.810
5/8	Piston	37,646	43.5	94.954
3/4–3	Disc	262	31.5	36.221
3/4–4	Piston	2,955	43.5	97.369
2–6	Other	112	39.5	84.976
TOTAL		43,031		

a water area of 107 sq.mi., and, with the Lake of the Woods, constitutes a supply which may be said to be virtually inexhaustible.

The intake at Shoal Lake is a concrete chamber with trash racks, screens and stop logs for control. The aqueduct, 96.5 mi. in total length from the lake to a point about 16 mi. east of the city's reservoir, consists of arch gravity sections varying from 6 ft. 4¾ in. by 5 ft. 4¾ in. to 10 ft. 9 in. by 9 ft., depending on the slope. Its designed capacity was 85 mgd. but tests subsequently made indicate that its actual capacity is about 100 mgd.

From the end of the gravity section, 16 mi. east of the city, the conduit continues as an 8-ft. reinforced concrete pipe of equivalent capacity for a distance of 4 mi. to a proposed reservoir site at Deacon. Continuing 9.3 mi. to the Red River the reinforced concrete pipe is 66 in. in diameter, with a capacity of 52 mgd., and thence continues 2.4 mi. as a 48-in. pipe, having a capacity of 30 mgd. to the reservoirs. When consumption requirements dictate, booster pumping is proposed at the Red River crossing.

The Greater Winnipeg Water District's 48-in. main terminates in reservoirs located within the city from which the supply is pumped by the city with-

TABLE 3

SUMMARY OF SERVICES

WINNIPEG, MANITOBA

Size. in.	Kind	No. of Feet Installed	No. of Feet Identified	No. of Feet Retired	No. of Feet in Service	Average Age, yr.
½		259	156	156	0	
⅝		33	33	33	0	
¾	Galvanized-iron	2,123	1,490	1,490	0	
1		655	399	399	0	
1¼		28	0	0	0	
1½		132	98	98	0	
½		6,017	5,190	5,190	0	
⅝		112	112	112	0	
¾		19,186	17,139	17,139	0	
1		4,109	2,944	2,944	0	
1¼	Wrought-iron	163	163	163	0	
1½		286	266	266	0	
2		651	605	605	0	
2½		123	66	66	0	
3		153	153	153	0	
½		657,933	655,752	101,050	554,702	29.8
⅝		260,603	259,905	39,445	220,460	32.8
¾	Lead	109,297	107,737	21,166	86,571	28.7
1		51,411	51,054	5,754	45,300	28.5
1½		122	122	18	104	32.5
2		421	421	77	344	24.6
½		77,625	77,556	652	76,904	12.3
⅝		17,765	17,659	132	17,527	12.0
¾		93,975	93,901	407	93,494	4.8
1	Copper	14,832	14,832	304	14,528	8.0
1¼		344	344	0	344	2.5
1½		593	593	0	593	5.0
2		2,313	2,313	0	2,313	10.2
3		460	460	185	275	42.4
4	Cast-iron	11,684	11,674	413	11,261	28.9
6		7,243	7,243	55	7,188	19.7
8		739	739	0	739	16.9
TOTAL		1,341,390	1,331,119	198,472	1,132,647	26.3
Percentage of Total			100.00	14.67	85.33	

TABLE 3 (contd.)

Mortality Survival Ratios

Size, *in.*	Kind	No. of Feet	Period Covered, *yr.*	Percentage
½-¾ 1-3	Galvanized-iron and Wrought-iron	24,120 4,694	38.5 34.5	0.000 0.000
½ ⅝ ¾ 1-2	Lead	655,752 259,905 107,737 51,597	48.5 47.5 48.5 47.5	63.600 72.638 60.416 82.697
¾ ½-2 (excl. ¾)	Copper	93,901 113,297	15.5 17.5	98.322 98.870
3-8	Cast-iron	20,116	55.5	91.934
TOTAL		**1,331,119**		
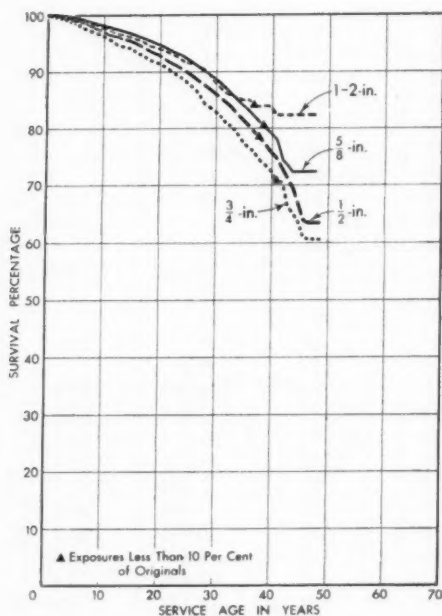
FIG. 3. Mortality Survival Curve—½-2-in. Lead Services—Winnipeg, Manitoba

BASE: Feet   SURVIVAL: 1894–1942

SIZE *in.*	EXPOSURES *ft.*	RETIREMENTS *ft.*
½	655,752	101,050
⅝	259,905	39,441
¾	107,737	21,166
1-2	51,597	5,849

out treatment other than algal control and ammonia and chlorination to the distribution system. The original covered concrete reservoir of 6-mil.gal. capacity was built in 1906 and abandoned in 1929. There are two reservoirs now in service; one, a concrete covered reservoir of 18-mil.gal. capacity, was constructed in 1913, and the other, an open concrete 40-mil.gal. reservoir was constructed in 1930.

The existing high-lift pumping station, constructed in 1930, replaced a steam turbo-generated electric station constructed in 1901. Pumping equipment consists of six motor-driven centrifugal pumps having a total rated capacity of 45 mgd. Power is secured chiefly from the city's hydro-electric system but standby connections are maintained with several private sources.

In addition the city operates an auxiliary electric power and central steam heating plant adjacent to the pumping station which can furnish power in emergencies.

The normal pressure maintained at the pumping station is about 75 psi. In addition to the normal water distribution system the city has a separate

TABLE 4

CAUSES OF RETIREMENTS OF CAST-IRON UNLINED MAINS
WINNIPEG, MANITOBA

Size, in.	Feet Retired	Cause of Retirement—*Percentage of Total*			
		Wear and Tear	Inadequacy	Obsolescence	Action of Public Authority
4	58,955	83.2	0.7	13.7	12.4
5	9,005	100.0			
6	26,475	61.8	3.7	14.2	20.3
8	20,856	74.0	1.4	18.0	6.6
10	532	9.2		66.4	24.4
12	3,458			21.0	79.0
14	45				100.0
18	1,113				100.0
20	148				100.0
TOTAL	120,587	74.6	1.4	13.8	10.2

fire service system started in 1908 which serves the principal mercantile and industrial areas and is used for fire protection purposes only. This system has an independent connection to the Shoal Lake conduit and, through booster pumping, maintains a pressure of about 75 psi. in the fire mains. This in turn can be raised to as high as 300 lb. when required.

The main distribution system within the city consists of approximately 331.13 mi. of mains 3 to 36 in. in diameter (inclusive of 12.8 mi. in the high-pressure system), predominantly Class C, pit-cast, tar-coated pipe laid with lead joints with a cover of about 7 ft. Equivalent class asbestos-cement and bolted-joint "Universal" cast-iron pipe has lately been used. Only a small amount of centrifugally-cast cast-iron pipe has been used.

There are 40,794 service connections which, with the exception of the larger cast-iron services and recent (since 1927) copper installations, are of lead. The city's system has 5,375 valves.

2,737 hydrants and 40,471 meters as of the date of the study. Active services are about 100 per cent metered, and these meters account for approximately 80 per cent of the total amount of water purchased.

Basis of Study

The records of installation and retirement of pipe, in the form of field books, are substantially complete from the original date of construction in 1882 to date.

The records of meters are substantially complete from 1899 to date and of services from 1882 to date. Class B facilities are not included in this study.

Mortality Survival Study

Mortality studies of mains, meters and services were made. Table 1 is a summary of the pipe installed, the amount retired and that still in service, as well as other pertinent data relative thereto. Figure 1 shows the mortality survival curves covering the rec-
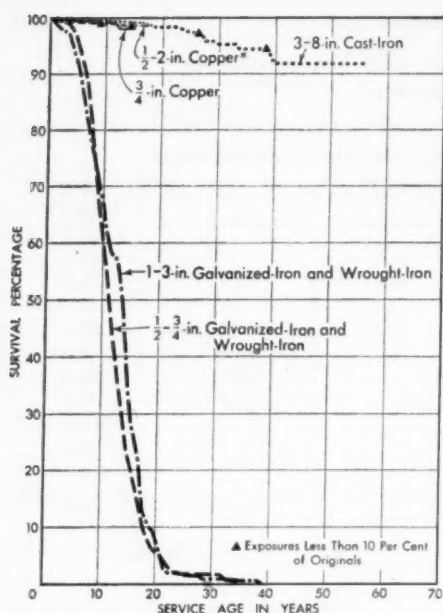
FIG. 4.—Mortality Survival Curve—½-8-in.
Services Other Than Lead—
Winnipeg, Manitoba

BASE: Feet　　　SURVIVAL: 1884-1942

SIZE in.	KIND	EXPO- SURES ft.	RETIRE- ments ft.
½-¾	Galvanized-Iron and Wrought-Iron	24,120	24,120
1-3	Galvanized-Iron and Wrought-Iron	4,694	4,694
¾	Copper	93,901	407
½-2	Copper*	113,297	1,096
3-8	Cast-Iron	20,116	653

* Excluding ¾-in.

ord of the amount and sizes of pipe grouped as shown.

Tables 2 and 3 are similar summaries of meters and services and Figs. 2, 3 and 4 present the applicable mortality survival curves.

Causes of Retirement

The causes of retirement of mains have been determined and classified under four general divisions as shown in Table 4. Of the total retirements of water mains 74.6 per cent were caused by wear and tear, 1.4 per cent by inadequacy, 13.8 per cent by obsolescence and 10.2 per cent by the action of public authorities. Two major factors have been influential in causing retirement of pipe because of wear and tear. The character of the soil in the Red River Valley has had much to do with the disintegration of pipe material. The soil contains certain soluble salts, including sulfates of sodium, magnesium and calcium. As a result, disintegration of the pipe has been relatively rapid.

The other major factor causing disintegration of pipe material has been electrolysis. Experts investigated this influence in 1906, 1909 and 1915, and concluded that electrolysis was particularly active in Winnipeg and a considerable number of retirements of pipe have been caused by its action.

While an analysis of the causes of retirement of meters has not been made, the retirement of large numbers of disc meters has been the result of standardization on the piston type meter. Further, in repairing meters, whenever a new upper or lower casing is renewed the original meter is considered retired, although a major part of such meter may remain in service.

Spot checks were made to determine the cause of retirement of ½-1-in. lead services by analyzing the retirements made at six-year intervals. Table 5 shows the results of the analysis with the retirements separated into five classifications.

Acknowledgments

The collection and compilation of data relative to the installation and re-

TABLE 5
CAUSES OF RETIREMENT OF LEAD SERVICES
WINNIPEG, MANITOBA

Size, in.	Cause of Retirement	No. of Feet Retired Installed in Year						Total No. of Feet Retired	Percentage of Total
		1894	1900	1906	1912	1918	1924		
¾	Not used	835	828	3,060	414	16	34	5,187	21.6
	Inadequate	160	290	1,439	154	28		2,071	8.7
	Street paving		92	28	186			306	1.2
	Corrosion	1,277	5,050	6,720	2,491	192	182	15,912	66.1
	Other	163	178	55	138	46		580	2.4
	TOTAL	2,435	6,438	11,302	3,382	282	216	24,056	100.0
¾	Not used		425	1,620	192		14	2,251	27.5
	Inadequate		106	166				272	3.3
	Street paving			168	14			182	2.2
	Corrosion		941	2,829	1,460			5,230	63.8
	Other		131	104	24			259	3.2
	TOTAL		1,603	4,887	1,690		14	8,194	100.0
¾	Not used	173	330	824	192	102	84	1,705	35.4
	Inadequate	15		168			46	229	4.7
	Street paving			17	14		52	83	1.8
	Corrosion	466	398	435	1,187			2,486	51.5
	Other	126	151				42	319	6.6
	TOTAL	780	879	1,444	1,393	102	224	4,822	100.0
1	Not used			109	90	163	264	686	43.5
	Inadequate			28	84			112	7.1
	Street paving				146			146	9.3
	Corrosion			251	190	43	149	633	40.1
	TOTAL			448	510	206	413	1,577	100.0
TOTAL	Not used	1,008	1,583	5,673	888	281	396	9,829	25.4
	Inadequate	175	396	1,801	238	28	46	2,684	7.0
	Street paving		92	213	360		52	717	1.9
	Corrosion	1,743	6,389	10,235	5,328	235	331	24,261	62.7
	Other	289	460	159	162	46	42	1,158	3.0
	TOTAL	3,215	8,920	18,081	6,976	590	867	38,649	100.0

tirement of facilities in Winnipeg were made under the general direction of Walter M. Scott, Chairman of Commissioners, Greater Winnipeg Water District, and a member of the Committee on Survival and Retirement Experience With Water Works Facilities. H. Shand, Engineer of the Winnipeg Water District, and W. D. Hurst, City Engineer (at the time of the study, Engineer of Water Works), were in charge of abstracting the records.

Summary of Installations and Retirements
Winnipeg, Manitoba

MAINS

3-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1942	199	199	0
Total	199	199	0

4-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1882	2,021	634	1,387
1883	3,606	935	2,671
1884	8,105	3,587	4,518
1885	2,782	852	1,930
1886	312	312	0
1887	4,375	634	3,741
1888	13,276	3,642	9,634
1889	6,835	3,872	2,963
1890	1,790	609	1,181
1891	2,495	745	1,750
1892	2,427	352	2,075
1893	1,788	495	1,293
1894	2,287	0	2,287
1895	261	261	0
1899	18,065	11,421	6,644
1900	36,228	31,496	4,732
1901	7,643	5,777	1,866
1902	5,990	5,207	783
1903	7,187	6,152	1,035
1904	16,134	13,984	2,150
1905	32,546	28,501	4,045
1906	4,009	3,136	873
1907	6,375	5,097	1,278
1908	1,479	1,401	78
1909	1,046	1,046	0
1910	832	832	0
1912	219	219	0
1913	1,081	1,040	41
1914	212	212	0
1919	12	12	0
1923	610	610	0
1924	1,037	1,037	0
1925	1,047	1,047	0
1927	51	51	0
1929	11	11	0
1936	62	62	0
1939	25	25	0

4-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet Installed	Feet In Service	Feet Retired
1941	666	666	0
1942	209	209	0
Total	195,136	136,181	58,955

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1882	39	1914	1,204	1924	64	1938
	80	1939				
1883	1,470	1924	1,201	1939		
1884	64	1906	567	1909	772	1911
	569	1923	2,294	1924	252	1936
1885	100	1907	20	1911	1,240	1930
	570	1939				
1887	20	1912	3,068	1924	653	1927
1888	222	1907	80	1911	2,761	1923
	518	1924	398	1927	1,880	1929
	1,686	1930	400	1934	1,088	1939
	601	1940				
1889	28	1918	1,662	1922	502	1923
	771	1924				
1890	66	1938	1,115	1939		
1891	940	1914	633	1923	170	1929
	7	1936				
1892	1,329	1921	351	1923	395	1930
1893	263	1922	80	1923	950	1939
1894	2,075	1924	212	1939		
1899	253	1915	1,757	1922	247	1924
	512	1928	1,170	1933	58	1937
	2,647	1939				
1900	84	1904	1,795	1923	1,177	1924
	128	1929	618	1935	46	1936
	711	1939	173	1941		
1901	921	1935	945	1939		
1902	360	1929	403	1935	20	1939
1903	232	1923	342	1928	65	1935
	396	1939				
1904	39	1910	324	1926	332	1930
	397	1932	1,058	1939		
1905	27	1913	329	1922	441	1930
	266	1937	2,982	1939		
1906	64	1923	619	1924	190	1934
1907	10	1909	330	1936	15	1937
	923	1939				
1908	20	1913	58	1937		
1913	41	1929				

5-IN. CAST-IRON UNLINED MAINS

Year Installed	Feet Installed	In Service	Retired		Year Installed	Feet	Year	Feet	Year
1883	1,790	0	1,790		1883	1,790	1924		
1886	1,677	1,677	0		1887	1,637	1927	1,553	1939
1887	4,143	953	3,190		1889	1,729	1922	1,090	1939
1888	1,959	1,959	0		1891	1,206	1939		
1889	2,819	0	2,819						
1891	1,737	531	1,206						
1893	650	650	0						
1942	0	0	0						
TOTAL	14,775	5,770	9,005						

6-IN. CAST-IRON UNLINED MAINS

Year Installed	Feet Installed	In Service	Retired		Year Installed	Feet Installed	In Service	Retired
1882	10,814	9,075	1,739		1916	2,957	2,957	0
1883	2,610	2,045	565		1917	2,495	2,495	0
1884	436	0	436		1918	320	309	11
1887	1,152	663	489		1919	6,932	6,766	166
1888	8,808	7,486	1,322		1920	5,409	5,409	0
1889	978	329	649		1921	7,900	7,900	0
1890	1,827	48	1,779		1922	13,553	13,553	0
1891	1,869	1,542	327		1923	16,597	16,028	569
1892	1,368	330	1,038		1924	16,526	16,526	0
1895	114	114	0		1925	4,418	4,418	0
1896	360	360	0		1926	4,465	4,335	130
1899	44,696	39,114	5,582		1927	4,146	4,146	0
1900	24,142	22,731	1,411		1928	3,840	3,840	0
1901	25,687	24,064	1,623		1929	13,677	13,677	0
1902	38,074	37,237	837		1930	6,532	6,484	48
1903	23,549	21,079	2,470		1931	4,154	4,154	0
1904	38,737	37,625	1,112		1932	4,446	4,446	0
1905	113,233	112,025	1,208		1933	400	400	0
1906	59,083	59,083	0		1934	610	610	0
1907	90,434	88,905	1,529		1935	2,795	2,795	0
1908	30,242	30,242	0		1937	237	237	0
1909	32,462	31,693	769		1938	513	513	0
1910	51,334	50,896	438		1939	20,477	20,477	0
1911	56,268	56,257	11		1940	1,008	1,008	0
1912	40,641	40,484	157		1941	7,135	7,135	0
1913	55,078	55,078	0		1942	213	213	0
1914	41,765	41,705	60					
1915	4,456	4,456	0		TOTAL	951,972	925,497	26,475

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year		Year Installed	Feet	Year	Feet	Year	Feet	Year
1882	1,739	1939						1888	52	1919	590	1934	148	1938
1883	565	1924							532	1939				
1884	436	1939						1889	649	1922				
1887	489	1939						1890	608	1907	150	1929	1,021	1939

6-IN. CAST-IRON UNLINED MAINS (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1891	66	1911	261	1939			1907	1,338	1922	20	1931	34	1932
1892	888	1935	150	1940				5	1934	86	1936	46	1939
1899	46	1921	514	1922	23	1927	1909	567	1924	202	1940		
	1,305	1929	251	1935	24	1936	1910	80	1931	358	1932		
	3,419	1939					1911	11	1924				
1900	709	1934	702	1939			1912	52	1914	105	1932		
1901	482	1905	619	1910	150	1919	1914	60	1924				
	372	1921					1918	11	1941				
1902	56	1910	304	1932	477	1941	1919	166	1924				
1903	21	1909	1,622	1935	364	1939	1923	569	1940				
	463	1942					1926	130	1939				
1904	650	1911	462	1939			1930	48	1940				
1905	142	1910	70	1913	174	1932							
	12	1933	810	1939									

8-IN. CAST-IRON UNLINED MAINS

Year Installed	Feet Installed	In Service	Retired	Year Installed	Installed	In Service	Retired
1882	13,119	2,451	10,668	1920	3,033	3,033	0
1883	2,028	0	2,028	1921	4,360	4,360	0
1887	1,492	569	923	1922	809	809	0
1889	3,988	1,266	2,722	1923	1,385	1,385	0
1899	15,342	14,820	522	1924	15,320	15,320	0
1900	11,543	11,310	233	1925	159	159	0
1901	2,940	195	2,745	1926	5,868	5,868	0
1902	7,787	7,787	0	1927	5,208	5,208	0
1903	2,282	2,282	0	1928	4,493	4,493	0
1904	6,129	5,792	337	1929	2,281	2,281	0
1905	6,591	6,591	0	1930	8,107	8,107	0
1906	5,936	5,279	657	1931	50	50	0
1907	1,753	1,753	0	1932	5,778	5,778	0
1908	15,152	15,152	0	1935	639	639	0
1909	7,951	7,951	0	1936	13	13	0
1910	10,559	10,548	11	1937	19	19	0
1911	11,216	11,216	0	1939	7,748	7,748	0
1912	14,904	14,894	10	1940	778	778	0
1913	20,390	20,390	0	1941	112	112	0
1914	9,049	9,049	0	1942	0	0	0
1915	1,473	1,473	0				
1916	1,968	1,968	0	TOTAL	244,035	223,179	20,856
1919	4,283	4,283	0				

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1882	300	1904	3,634	1923	2,296	1937	1900	225	1921	8	1939		
	4,438	1939					1901	2,745	1935				
1883	2,028	1924					1904	107	1912	220	1935	10	1938
1887	725	1922	198	1938			1906	285	1911	372	1937		
1889	2,722	1938					1910	11	1937				
1899	425	1904	97	1913			1912	10	1936				

10-IN. CAST-IRON UNLINED MAINS

Year Installed	Feet Installed	In Service	Retired	Year Installed	Feet Installed	In Service	Retired
1882	905	905	0	1924	1,699	1,699	0
1891	2,840	2,507	333	1925	1,099	1,099	0
1899	9,477	9,408	69	1926	3,124	3,124	0
1900	5,309	5,309	0	1927	1,032	1,032	0
1901	2,202	2,202	0	1928	719	719	0
1902	7,606	7,606	0	1929	1,586	1,586	0
1903	4,286	4,286	0	1930	2,306	2,306	0
1904	5,705	5,705	0	1931	3,399	3,399	0
1905	10,072	10,072	0	1932	739	739	0
1906	5,411	5,411	0	1933	175	175	0
1907	8,281	8,281	0	1935	540	540	0
1908	10,246	10,246	0	1936	143	143	0
1909	1,768	1,768	0	1937	2,298	2,298	0
1910	6,055	6,055	0	1938	201	201	0
1911	7,899	7,769	130	1939	616	616	0
1912	11,899	11,899	0	1942	21	21	0
1913	20,440	20,440	0				
1914	7,934	7,934	0	TOTAL	164,306	163,774	532
1915	3,829	3,829	0				
1916	1,384	1,384	0				
1917	1,138	1,138	0				
1919	1,106	1,106	0				
1920	2,000	2,000	0				
1921	283	283	0				
1922	1,180	1,180	0				
1923	5,354	5,354	0				

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1891	333	1926		
1899	20	1919	49	1939
1911	130	1936		

12-IN. CAST-IRON UNLINED MAINS

Year Installed	Feet Installed	In Service	Retired	Year Installed	Feet Installed	In Service	Retired
1882	2,675	0	2,675	1928	280	280	0
1899	5,768	5,684	84	1929	3,393	3,393	0
1901	2,248	2,248	0	1930	3,146	3,146	0
1902	1,577	1,577	0	1931	8	8	0
1903	1,137	1,137	0	1932	2,062	2,062	0
1904	557	557	0	1935	3,441	3,441	0
1905	2,110	2,058	52	1938	20	20	0
1906	2,501	2,493	8	1939	2,540	2,540	0
1907	8,176	8,093	83	1940	41	41	0
1908	11,184	11,134	50	1941	157	157	0
1909	7,976	7,887	89	1942	7	7	0
1910	3,282	3,167	115				
1911	2,393	2,165	228	TOTAL	94,684	91,226	3,458
1912	1,129	1,055	74				
1913	7,266	7,266	0				
1914	5,291	5,291	0				
1915	2,380	2,380	0				
1916	736	736	0				
1917	1,245	1,245	0				
1919	2,083	2,083	0				
1920	345	345	0				
1921	811	811	0				
1922	1,679	1,679	0				
1925	3,620	3,620	0				
1926	865	865	0				
1927	555	555	0				

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1882	170	1901	2,505	1905
1899	84	1904		
1905	52	1932		
1906	8	1941		
1907	83	1922		
1910	115	1918		
1911	228	1919		
1912	74	1922		

14-in. Cast-Iron Unlined Mains

Year Installed	Installed	In Service	Retired
1889	2,406	2,406	0
1899	6,548	6,548	0
1900	294	294	0
1902	1,718	1,718	0
1903	2,032	2,032	0
1905	6,361	6,316	45
1907	5,795	5,795	0
1908	1,706	1,706	0
1911	2,251	2,251	0
1913	1,259	1,259	0
1914	1,383	1,383	0
1919	44	44	0
1923	2,998	2,998	0
1924	1,241	1,241	0
1929	154	154	0
1930	3,081	3,081	0
1932	9	9	0
1939	934	934	0
1941	54	54	0
1942	0	0	0
TOTAL	40,268	40,223	45

Retirements by Years

Year Installed	Feet	Year
1905	45	1919

16-in. Cast-Iron Unlined Mains

Year Installed	Feet		
	Installed	In Service	Retired
1899	5,126	5,126	0
1902	213	213	0
1905	1,935	1,935	0
1906	2,914	2,914	0
1907	5,872	5,872	0
1908	1,446	1,446	0
1909	772	772	0
1939	590	590	0
1942	0	0	0
TOTAL	18,868	18,868	0

18-in. Cast-Iron Unlined Mains

Year Installed	Feet		
	Installed	In Service	Retired
1899	1,863	1,863	0
1905	5,236	4,219	1,017
1906	6,442	6,346	96
1907	579	579	0
1908	257	257	0

18-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet		
	Installed	In Service	Retired
1909	3,380	3,380	0
1911	2,081	2,081	0
1912	1,000	1,000	0
1919	7,172	7,172	0
1930	11,356	11,356	0
1932	295	295	0
1938	35	35	0
1939	54	54	0
1942	0	0	0
TOTAL	39,750	38,637	1,113

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1905	847	1910	170	1930
1906	96	1941		

20-in. Cast-Iron Unlined Mains

Year Installed	Feet		
	Installed	In Service	Retired
1899	4,001	3,853	148
1919	17	17	0
1940	182	182	0
1942	0	0	0
TOTAL	4,200	4,052	148

Retirements by Years

Year Installed	Feet	Year
1899	148	1940

24-in. Cast-Iron Unlined Mains

Year Installed	Feet		
	Installed	In Service	Retired
1919	11	11	0
1942	0	0	0
TOTAL	11	11	0

6-in. Asbestos-Cement Mains

Year Installed	Feet		
	Installed	In Service	Retired
1940	571	571	0
1942	0	0	0
TOTAL	571	571	0

10-in. Asbestos-Cement Mains

Year Installed	Feet Installed	In Service	Retired
1937	935	935	0
1938	2,703	2,703	0
1939	5,216	5,216	0
1942	0	0	0
Total	8,854	8,854	0

14-in. Asbestos-Cement Mains

Year Installed	Feet Installed	In Service	Retired
1932	431	431	0
1942	0	0	0
Total	431	431	0

18-in. Asbestos-Cement Mains

Year Installed	Feet Installed	In Service	Retired
1932	752	752	0
1939	107	107	0
1942	0	0	0
Total	859	859	0

10-in. Cast-Iron Flexible Joint Mains

Year Installed	Feet Installed	In Service	Retired
1904	314	314	0
1908	525	525	0
1942	0	0	0
Total	839	839	0

12-in. Cast-Iron Flexible Joint Mains

Year Installed	Feet Installed	In Service	Retired
1925	782	782	0
1942	0	0	0
Total	782	782	0

18-in. Victaulic Unlined Mains

Year Installed	Feet Installed	In Service	Retired
1939	113	113	0
1942	0	0	0
Total	113	113	0

24-in. Concrete Mains

Year Installed	Feet Installed	In Service	Retired
1938	3,899	3,899	0
1942	0	0	0
Total	3,899	3,899	0

36-in. Steel Concrete Covered Mains

Year Installed	Feet Installed	In Service	Retired
1919	1,200	1,200	0
1942	0	0	0
Total	1,200	1,200	0

METERS

⅝-in. Disc Meters

Year Installed	Number Installed	In Service	Retired	Year Installed	Number Installed	In Service	Retired
1900	1	0	1	1912	7	1	6
1901	1	0	1	1913	54	3	51
1902	81	0	81	1914	3	0	3
1904	115	0	115	1915	21	5	16
1906	203	104	99	1916	14	6	8
1907	6	0	6	1917	4	1	3
1908	4	2	2	1918	7	4	3
1909	999	320	679	1919	7	3	4
1910	3	1	2	1920	10	3	7
1911	2	1	1	1921	6	2	4

⅝-IN. DISC METERS (contd.)

Year Installed	Number			Year Installed	Number		
	Installed	In Service	Retired		Installed	In Service	Retired
1922	6	1	5	1936	6	6	0
1923	7	3	4	1937	1	1	0
1924	5	2	3	1938	1	1	0
1925	5	2	3	1939	4	4	0
1926	6	3	3	1940	4	4	0
1927	2	1	1	1941	68	68	0
1928	2	0	2	1942	356	356	0
1929	4	0	4				
1930	10	3	7	SUBTOTAL	2,056	924	1,132
1931	1	1	0	Unknown	43	3	40
1933	5	2	3				
1934	12	7	5	TOTAL	2,099	927	1,172
1935	3	3	0				

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year	Year Installed	Number	Year	Number	Year	Number	Year
1900	1	1900					1909	37	1940	12	1941	15	1942
1901	1	1908					1910	1	1925	1	1936		
1902	1	1904	7	1906	37	1907	1911	1	1922				
	7	1908	12	1909	2	1910	1912	1	1915	1	1918	1	1919
	1	1911	1	1912	4	1913		1	1922	1	1923	1	1941
	3	1914	2	1915	2	1918	1913	1	1914	14	1915	12	1916
	1	1929	1	1930				4	1917	2	1918	2	1919
1904	1	1904	2	1905	8	1906		2	1920	2	1922	1	1925
	22	1907	7	1908	5	1909		1	1926	1	1928	1	1929
	5	1910	4	1911	6	1912		2	1932	1	1933	1	1936
	12	1913	13	1914	9	1915		3	1939	1	1941		
	3	1916	5	1917	1	1919	1914	2	1934	1	1935		
	1	1922	1	1926	1	1930	1915	2	1923	1	1926	1	1929
	3	1931	4	1932	1	1933		2	1934	1	1938	9	1940
	1	1935					1916	1	1919	1	1920	1	1924
1906	2	1907	1	1908	2	1909		1	1934	1	1938	3	1939
	3	1910	3	1911	2	1912	1917	1	1931	1	1936	1	1937
	1	1914	2	1915	1	1916	1918	1	1920	1	1934	1	1937
	2	1917	2	1918	4	1919	1919	1	1919	1	1920	1	1928
	3	1920	3	1921	1	1922		1	1940				
	1	1923	1	1924	1	1925	1920	2	1921	1	1924	3	1933
	3	1926	4	1930	5	1931		1	1934				
	6	1932	15	1933	2	1934	1921	1	1925	1	1934	1	1936
	5	1935	7	1936	2	1937		1	1939				
	4	1938	4	1939	5	1940	1922	3	1933	2	1935		
	2	1942					1923	2	1933	1	1937	1	1939
1907	4	1907	1	1908	1	1909	1924	2	1935	1	1940		
1908	1	1913	1	1914			1925	1	1930	1	1932	1	1939
1909	3	1910	1	1911	4	1912	1926	1	1929	2	1933		
	4	1913	4	1914	8	1915	1927	1	1929				
	15	1916	6	1917	6	1918	1928	1	1933	1	1940		
	5	1919	1	1920	2	1921	1929	2	1932	1	1933	1	1941
	5	1922	7	1923	1	1924	1930	1	1931	2	1933	1	1934
	2	1925	2	1926	1	1927		1	1936	1	1937	1	1940
	4	1928	23	1929	30	1930	1933	1	1939	2	1940		
	41	1931	55	1932	62	1933	1934	1	1935	2	1936	1	1937
	68	1934	54	1935	58	1936		1	1939				
	40	1937	50	1938	53	1939							

¾-IN. DISC METERS

Year Installed	Number				Retirements by Years					
	Installed	In Service	Retired	Year Installed	Number	Year	Number	Year	Number	Year
1901	1	0	1	1901	1	1906				
1902	8	0	8	1902	2	1906	2	1907	1	1909
1934	1	1	0		1	1910	1	1911	1	1912
1939	3	3	0							
1940	10	10	0							
1941	7	7	0							
1942	21	21	0							
SUBTOTAL	51	42	9							
Unknown	3	2	1							
TOTAL	54	44	10							

1-IN. DISC METERS

Year Installed	Number				Retirements by Years					
	Installed	In Service	Retired	Year Installed	Number	Year	Number	Year	Number	Year
1902	1	0	1	1902	1	1914				
1911	22	15	7	1911	2	1911	2	1925	1	1927
1912	47	21	26		2	1938				
1925	1	1	0	1912	1	1923	3	1925	3	1926
1934	4	3	1		2	1927	5	1928	3	1929
1938	2	2	0		1	1930	2	1933	1	1935
1939	16	16	0		4	1938	1	1940		
1940	17	17	0	1934	1	1940				
1941	7	7	0							
1942	0	0	0							
SUBTOTAL	117	82	35							
Unknown	19	0	19							
TOTAL	136	82	54							

1½-IN. DISC METERS

Year Installed	Number				Retirements by Years					
	Installed	In Service	Retired	Year Installed	Number	Year	Number	Year	Number	Year
1911	5	3	2	1911	1	1925	1	1933		
1912	4	1	3	1912	1	1923	1	1933	1	1938
1914	1	0	1	1914	1	1924				
1916	3	1	2	1916	1	1928	1	1940		
1934	1	1	0							
1939	3	3	0							
1940	5	5	0							
1941	4	4	0							
1942	4	4	0							
SUBTOTAL	30	22	8							
Unknown	24	0	24							
TOTAL	54	22	32							

2-IN. DISC METERS

Year Installed	Installed	In Service	Retired
1900	1	0	1
1911	9	3	6
1912	14	1	13
1913	8	1	7
1914	8	2	6
1915	2	0	2
1917	1	1	0
1921	1	1	0
1934	1	1	0
1938	1	1	0
1940	1	1	0
1941	7	7	0
1942	2	2	0
SUBTOTAL	56	21	35
Unknown	3	0	3
TOTAL	59	21	38

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1900	1	1907				
1911	1	1912	1	1921	3	1934
	1	1941				
1912	1	1917	1	1922	2	1924
	6	1934	1	1937	2	1938
1913	1	1922	1	1923	1	1924
	2	1925	2	1931		
1914	1	1923	3	1924	1	1925
	1	1927				
1915	1	1923	1	1924		

3-IN. DISC METERS

Year Installed	Installed	In Service	Retired
1901	3	0	3
1913	4	2	2
1935	1	1	0
1942	0	0	0
SUBTOTAL	8	3	5
Unknown	1	0	1
TOTAL	9	3	6

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1901	1	1911	1	1912	1	1916
1913	2	1941				

⅝-IN. PISTON METERS

Year Installed	Installed	In Service	Retired	Year Installed	Installed	In Service	Retired
1899	909	893	16	1915	632	611	21
1900	490	482	8	1916	29	24	5
1901	115	115	0	1917	246	239	7
1902	35	35	0	1918	208	192	16
1903	842	824	18	1919	99	96	3
1904	1,447	1,399	48	1920	160	152	8
1905	1,336	1,305	31	1921	449	441	8
1906	3,113	2,859	254	1922	605	586	19
1907	1,502	1,248	254	1923	1,108	1,083	25
1908	815	808	7	1924	663	649	14
1909	3,760	3,541	219	1925	331	329	2
1910	2,569	2,443	126	1926	673	667	6
1911	2,553	2,467	86	1927	681	677	4
1912	2,438	2,354	84	1928	1,005	1,002	3
1913	3,271	3,216	55	1929	809	804	5
1914	2,471	2,431	40	1930	777	774	3

⅝-IN. PISTON METERS (contd.)

Year Installed	Installed	In Service	Retired	Year Installed	Installed	In Service	Retired
1931	463	462	1	1940	23	23	0
1932	356	355	1	1941	222	222	0
1933	80	79	1	1942	77	77	0
1934	84	82	2				
1935	62	61	1	SUBTOTAL	37,646	36,245	1,401
1936	90	90	0	Unknown	291	5	286
1937	26	26	0				
1938	11	11	0	TOTAL	37,937	36,250	1,687
1939	11	11	0				

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1899	1	1907	1	1912	1	1924
	2	1925	4	1928	3	1929
	1	1930	1	1932	1	1938
	1	1940				
1900	1	1906	1	1912	2	1922
	1	1926	1	1928	1	1929
	1	1933				
1903	1	1913	1	1923	1	1924
	2	1929	2	1930	1	1932
	1	1933	2	1934	2	1935
	1	1936	1	1938	1	1939
	1	1940	1	1941		
1904	1	1904	3	1910	1	1911
	9	1912	1	1916	1	1917
	1	1918	2	1921	2	1922
	1	1924	2	1925	1	1927
	3	1928	3	1929	1	1932
	4	1934	1	1935	2	1937
	1	1938	1	1939	2	1940
	3	1941	2	1942		
1905	1	1910	4	1912	2	1914
	1	1917	1	1925	1	1927
	3	1928	1	1929	1	1930
	2	1933	4	1934	4	1935
	2	1936	3	1940	1	1941
1906	1	1908	8	1909	7	1910
	11	1911	23	1912	4	1913
	3	1914	5	1915	9	1916
	5	1917	5	1918	5	1919
	1	1920	2	1921	2	1922
	7	1923	10	1924	10	1925
	6	1926	3	1927	8	1928
	7	1929	6	1930	1	1931
	6	1932	5	1933	22	1934
	13	1935	32	1936	8	1937
	4	1938	7	1940	7	1941
	1	1942				
1907	1	1908	15	1909	17	1910
	25	1911	12	1912	10	1913
	15	1914	15	1915	3	1916

Year Installed	Number	Year	Number	Year	Number	Year
1907	4	1917	2	1918	5	1919
	6	1920	1	1921	5	1922
	6	1923	5	1924	4	1925
	1	1926	5	1927	3	1928
	3	1929	5	1930	7	1931
	3	1932	9	1933	11	1934
	17	1935	16	1936	6	1937
	1	1938	3	1939	3	1940
	4	1941	6	1942		
1908	1	1920	1	1935	3	1936
	1	1938	1	1939		
1909	1	1909	1	1910	5	1911
	4	1912	3	1913	2	1914
	2	1915	7	1916	2	1917
	5	1918	2	1919	14	1920
	7	1921	8	1922	9	1923
	12	1924	5	1925	5	1926
	7	1927	8	1928	7	1929
	3	1930	4	1931	6	1932
	8	1933	14	1934	19	1935
	15	1936	8	1937	2	1938
	1	1939	5	1940	7	1941
	11	1942				
1910	10	1911	6	1912	1	1913
	3	1914	6	1915	3	1916
	2	1917	4	1918	1	1919
	1	1920	4	1921	7	1922
	10	1923	6	1924	3	1925
	2	1926	6	1928	3	1929
	5	1930	5	1931	1	1932
	3	1933	11	1934	5	1935
	8	1936	1	1937	2	1941
	7	1942				
1911	6	1911	11	1912	1	1913
	2	1914	3	1915	2	1916
	2	1918	2	1919	1	1920
	2	1921	5	1922	4	1923
	3	1924	1	1925	2	1926
	2	1927	1	1928	4	1929
	1	1930	4	1932	2	1933

¾-IN. PISTON METERS (contd.)

Retirements by Years (contd.)

Year Installed	Number	Year	Number	Year	Number	Year	Year Installed	Number	Year	Number	Year	Number	Year
1911	3	1934	1	1935	4	1936	1918	1	1924	1	1925	1	1926
	3	1939	4	1940	1	1941		2	1927	1	1929	1	1930
	9	1942						1	1931	1	1934	2	1936
1912	2	1912	2	1913	1	1914		1	1942				
	11	1915	12	1916	7	1917	1919	1	1921	1	1934	1	1942
	3	1918	3	1919	3	1921	1920	1	1922	1	1923	1	1928
	2	1923	2	1924	2	1925		1	1931	1	1934	1	1936
	2	1926	2	1927	2	1928		2	1942				
	2	1929	1	1931	1	1932	1921	1	1922	1	1924	1	1925
	3	1933	4	1934	3	1935		1	1926	1	1929	1	1936
	3	1936	1	1937	3	1938		1	1941	1	1942		
	3	1939	2	1941	3	1942	1922	1	1924	3	1927	2	1928
1913	2	1913	1	1915	3	1917		1	1930	2	1931	1	1934
	4	1918	4	1919	4	1920		2	1935	1	1941	6	1942
	3	1921	2	1922	3	1923	1923	1	1924	2	1925	1	1926
	2	1924	1	1925	1	1926		3	1927	1	1928	1	1929
	1	1927	4	1928	3	1929		1	1930	1	1933	1	1935
	2	1930	2	1932	4	1934		2	1936	1	1938	3	1941
	2	1935	1	1936	1	1938		7	1942				
	1	1940	4	1942			1924	3	1925	1	1926	2	1927
1914	1	1914	1	1917	1	1918		1	1928	1	1929	1	1931
	3	1919	2	1920	1	1921		1	1932	2	1935	1	1941
	2	1922	1	1923	1	1924		1	1942				
	1	1925	1	1926	5	1928	1925	1	1932	1	1937		
	1	1929	3	1932	2	1933	1926	1	1929	2	1930	1	1936
	6	1934	3	1936	1	1937		2	1942				
	1	1940	2	1941	1	1942	1927	2	1933	1	1940	1	1941
1915	1	1917	1	1920	7	1923	1928	1	1936	1	1938	1	1940
	1	1924	1	1925	1	1926	1929	1	1929	1	1933	1	1936
	1	1927	1	1928	2	1930		1	1938	1	1940		
	1	1933	2	1934	1	1935	1930	1	1934	1	1935	1	1942
	1	1938					1931	1	1936				
1916	1	1920	1	1922	1	1935	1932	1	1934				
	2	1942					1933	1	1934				
1917	1	1919	1	1925	2	1930	1934	2	1937				
	1	1931	1	1941	1	1942	1935	1	1936				
1918	1	1918	1	1921	2	1923							

¾-IN. PISTON METERS

Year Installed	Number			Year Installed	Number		
	Installed	In Service	Retired		Installed	In Service	Retired
1899	218	216	2	1909	70	70	0
1900	216	214	2	1910	59	58	1
1901	60	60	0	1911	46	42	4
1902	33	33	0	1912	50	49	1
1903	227	224	3	1913	82	77	5
1904	44	43	1	1914	39	39	0
1905	54	54	0	1915	22	21	1
1906	71	71	0	1916	4	3	1
1907	31	30	1	1917	1	1	0
1908	58	57	1	1918	5	4	1

¾-IN. PISTON METERS (contd.)

Year Installed	Installed	In Service	Retired	Year Installed	Installed	In Service	Retired
1920	3	3	0	1932	24	24	0
1921	5	5	0	1933	1	1	0
1922	3	3	0	1934	3	3	0
1923	6	6	0	1935	1	1	0
1924	3	2	1	1938	1	1	0
1925	7	7	0	1941	2	2	0
1926	5	5	0	1942	3	3	0
1927	24	24	0				
1928	29	29	0	SUBTOTAL	1,662	1,635	27
1929	62	62	0	Unknown	33	2	31
1930	59	58	1				
1931	31	30	1	TOTAL	1,695	1,637	58

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year	Year Installed	Number	Year	Number	Year	Number	Year
1899	1	1932	1	1938			1912	1	1920				
1900	1	1906	1	1930			1913	1	1918	1	1924	1	1926
1903	1	1919	1	1924	1	1939			1930	1	1942		
1904	1	1927					1915	1	1915				
1907	1	1925					1916	1	1920				
1908	1	1926					1918	1	1927				
1910	1	1925					1924	1	1927				
1911	1	1918	1	1925	1	1934	1930	1	1935				
	1	1942					1931	1	1934				

1-IN. PISTON METERS

Year Installed	Installed	In Service	Retired	Year Installed	Installed	In Service	Retired
1899	15	15	0	1921	4	4	0
1900	18	18	0	1922	9	8	1
1901	152	148	4	1923	11	11	0
1902	6	6	0	1924	6	6	0
1903	17	·16	1	1925	13	13	0
1904	11	11	0	1926	15	15	0
1905	26	25	1	1927	17	17	0
1906	48	48	0	1928	17	17	0
1907	32	31	1	1929	30	30	0
1908	4	4	0	1930	6	6	0
1909	13	13	0	1931	15	15	0
1910	40	36	4	1932	8	8	0
1911	6	5	1	1933	2	2	0
1912	25	25	0	1934	3	3	0
1913	77	77	0	1940	1	1	0
1914	47	47	0	1942	0	0	0
1915	22	22	0				
1916	4	4	0	SUBTOTAL	743	730	13
1917	6	6	0	Unknown	13	1	12
1918	4	4	0				
1919	8	8	0	TOTAL	756	731	25
1920	5	5	0				

1-IN. PISTON METERS (contd.)

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year	Year Installed	Number	Year	Number	Year	Number	Year
1901	1	1906	1	1921	1	1932	1910	1	1911	1	1913	1	1922
	1	1938						1	1940				
1903	1	1932					1911	1	1934				
1905	1	1934					1922	1	1930				
1907	1	1934											

1½-IN. PISTON METERS

Year Installed	Number Installed	In Service	Retired	Year Installed	Number Installed	In Service	Retired
1899	2	2	0	1924	7	7	0
1900	4	4	0	1925	7	7	0
1901	9	9	0	1926	13	12	1
1902	12	11	1	1927	15	15	0
1903	2	2	0	1928	24	24	0
1904	7	7	0	1929	23	23	0
1905	11	11	0	1930	12	12	0
1906	11	11	0	1931	9	9	0
1907	10	10	0	1932	4	4	0
1908	7	7	0	1933	3	3	0
1909	5	5	0	1935	1	1	0
1910	13	11	2	1936	2	2	0
1912	5	5	0	1937	1	1	0
1913	3	3	0	1942	0	0	0
1914	47	45	2				
1915	11	11	0	TOTAL	322	316	6
1916	2	2	0				
1917	4	4	0		Retirements by Years		
1918	8	8	0	Year			
1919	5	5	0	Installed	Number	Year	Number	Year
1920	6	6	0	1902	1	1937		
1921	3	3	0	1910	1	1935	1	1937
1922	4	4	0	1914	2	1936		
1923	10	10	0	1926	1	1929		

2-IN. PISTON METERS

Year Installed	Number Installed	In Service	Retired	Year Installed	Number Installed	In Service	Retired
1899	1	1	0	1912	2	2	0
1900	19	18	1	1913	5	5	0
1901	4	4	0	1914	3	3	0
1902	7	7	0	1915	6	5	1
1904	9	9	0	1916	8	8	0
1905	10	10	0	1917	5	5	0
1906	4	3	1	1918	7	7	0
1907	7	7	0	1919	1	1	0
1908	2	2	0	1920	3	2	1
1909	3	2	1	1921	5	5	0
1910	12	11	1	1922	10	10	0

2-IN. PISTON METERS (contd.)

Year Installed	Number Installed	In Service	Retired	Year Installed	Number Installed	In Service	Retired
1923	9	9	0	1937	1	1	0
1924	5	5	0	1938	1	1	0
1925	7	6	1	1939	3	3	0
1926	8	7	1	1940	5	5	0
1927	5	4	1	1942	0	0	0
1928	8	8	0		—	—	—
1929	8	7	1	SUBTOTAL	214	203	11
1930	9	8	1	Unknown	1	0	1
1931	9	9	0		—	—	—
1932	2	2	0	TOTAL	215	203	12
1933	1	1	0				

Retirements by Years

Year Installed	Number	Year	Year Installed	Number	Year
1900	1	1923	1925	1	1926
1906	1	1938	1926	1	1926
1909	1	1920	1927	1	1927
1910	1	1932	1929	1	1930
1915	1	1937	1930	1	1930
1920	1	1929			

3-IN. PISTON METERS

Year Installed	Number Installed	In Service	Retired
1901	3	3	0
1906	1	1	0
1911	2	1	1
1912	5	5	0
1926	1	1	0
1942	0	0	0
	—	—	—
SUBTOTAL	12	11	1
Unknown	1	0	1
	—	—	—
TOTAL	13	11	2

Retirements by Years

Year Installed	Number	Year
1911	1	1926

4-IN. PISTON METERS

Year Installed	Number Installed	In Service	Retired
1912	2	2	0
1942	0	0	0
	—	—	—
TOTAL	2	2	0

2-IN. CURRENT METERS

Year Installed	Number Installed	In Service	Retired
1905	3	0	3
1919	1	0	1
1942	0	0	0
	—	—	—
TOTAL	4	0	4

Retirements by Years

Year Installed	Number	Year	Number	Year
1905	1	1919	2	1934
1919	1	1920		

3-IN. CURRENT METERS

Year Installed	Number Installed	In Service	Retired
1903	1	1	0
1904	1	1	0
1908	3	3	0
1909	2	2	0
1910	1	1	0
1911	1	1	0
1912	3	2	1
1914	3	2	1

3-IN. CURRENT METERS (contd.)

Year	Number		
Installed	Installed	In Service	Retired
1915	3	3	0
1942	0	0	0
	—	—	—
SUBTOTAL	18	16	2
Unknown	1	0	1
	—	—	—
TOTAL	19	16	3

Retirements by Years

Year Installed	Number	Year
1912	1	1919
1914	1	1934

4-IN. CURRENT METERS

Year	Number		
Installed	Installed	In Service	Retired
1906	2	1	1
1908	1	1	0
1914	1	1	0
1915	2	2	0
1936	1	1	0
1942	0	0	0
	—	—	—
SUBTOTAL	7	6	1
Unknown	1	0	1
	—	—	—
TOTAL	8	6	2

Retirements by Years

Year Installed	Number	Year
1906	1	1935

6-IN. CURRENT METERS

Year	Number		
Installed	Installed	In Service	Retired
1926	1	1	0
1942	0	0	0
	—	—	—
TOTAL	1	1	0

3-IN. COMPOUND METERS

Year	Number		
Installed	Installed	In Service	Retired
1913	1	1	0
1915	5	5	0
1916	2	2	0
1917	1	1	0
1918	2	2	0
1919	1	1	0

3-IN. COMPOUND METERS (contd.)

Year	Number		
Installed	Installed	In Service	Retired
1920	5	5	0
1921	1	1	0
1922	5	5	0
1923	1	1	0
1924	3	3	0
1925	3	3	0
1926	6	6	0
1929	2	2	0
1930	3	3	0
1931	1	1	0
1932	1	1	0
1933	1	1	0
1934	1	1	0
1935	3	3	0
1936	1	1	0
1938	1	1	0
1939	1	1	0
1940	4	4	0
1942	0	0	0
	—	—	—
TOTAL	55	55	0

4-IN. COMPOUND METERS

Year	Number		
Installed	Installed	In Service	Retired
1913	1	1	0
1916	2	2	0
1918	1	1	0
1919	1	1	0
1920	1	1	0
1924	3	3	0
1926	2	2	0
1928	2	2	0
1929	1	1	0
1930	2	2	0
1931	4	4	0
1932	1	1	0
1938	1	1	0
1941	1	1	0
1942	0	0	0
	—	—	—
TOTAL	23	23	0

6-IN. COMPOUND METERS

Year	Number		
Installed	Installed	In Service	Retired
1920	1	1	0
1925	1	1	0
1928	1	1	0
1934	1	1	0
1942	0	0	0
	—	—	—
TOTAL	4	4	0

SERVICES

½-IN. GALVANIZED-IRON SERVICES

| Year | Feet | | |
Installed	Installed	In Service	Retired
1882	124	0	124
1883	32	0	32
1942	0	0	0
SUBTOTAL	156	0	156
Unknown	103	0	103
TOTAL	259	0	259

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1882	29	1895	47	1901	47	1916
1883	32	1901				

⅝-IN. GALVANIZED-IRON SERVICES

| Year | Feet | | |
Installed	Installed	In Service	Retired
1882	33	0	33
1942	0	0	0
TOTAL	33	0	33

Retirements by Years

Year Installed	Feet	Year
1882	33	1901

¾-IN. GALVANIZED-IRON SERVICES

| Year | Feet | | |
Installed	Installed	In Service	Retired
1882	509	0	509
1883	292	0	292
1884	689	0	689
1942	0	0	0
SUBTOTAL	1,490	0	1,490
Unknown	633	0	633
TOTAL	2,123	0	2,123

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1882	30	1891	105	1895	66	1898
	76	1900	48	1901	20	1904
	103	1905	20	1908	41	1909
1883	40	1894	103	1900	18	1903
	102	1905	29	1906		

¾-IN. GALVANIZED-IRON SERVICES (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year
1884	40	1893	114	1894	161	1895
	49	1896	46	1897	45	1898
	86	1900	102	1906	46	1912

1-IN. GALVANIZED-IRON SERVICES

| Year | Feet | | |
Installed	Installed	In Service	Retired
1882	34	0	34
1883	122	0	122
1884	243	0	243
1942	0	0	0
SUBTOTAL	399	0	399
Unknown	256	0	256
TOTAL	655	0	655

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1882	34	1896				
1883	42	1886	33	1900	47	1904
1884	105	1891	138	1894		

1¼-IN. GALVANIZED-IRON SERVICES

| Year | Feet | | |
Installed	Installed	In Service	Retired
Unknown	28	0	28
TOTAL	28	0	28

1½-IN. GALVANIZED-IRON SERVICES

| Year | Feet | | |
Installed	Installed	In Service	Retired
1882	98	0	98
1942	0	0	0
SUBTOTAL	98	0	98
Unknown	34	0	34
TOTAL	132	0	132

Retirements by Years

Year Installed	Feet	Year
1882	98	1903

½-IN. WROUGHT-IRON SERVICES

Year Installed	Installed	In Service	Retired
1884	46	0	46
1886	205	0	205
1887	1,065	0	1,065
1888	1,464	0	1,464
1889	933	0	933
1890	268	0	268
1891	451	0	451
1892	322	0	322
1893	436	0	436
1942	0	0	0
SUBTOTAL	5,190	0	5,190
Unknown	827	0	827
TOTAL	6,017	0	6,017

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1884	46	1895				
1886	73	1894	61	1895	71	1900
1887	37	1891	39	1893	180	1894
	136	1895	131	1896	43	1898
	138	1899	111	1900	110	1901
	46	1902	20	1903	28	1907
	46	1915				
1888	20	1889	46	1890	12	1892
	45	1893	145	1894	78	1895
	65	1897	37	1898	109	1899
	135	1900	318	1901	20	1902
	46	1903	92	1904	33	1905
	40	1906	46	1907	46	1908
	84	1909	18	1920		
1889	33	1893	103	1894	20	1895
	79	1896	46	1897	52	1898
	88	1899	114	1900	119	1901
	54	1902	129	1906	96	1909
1890	30	1897	16	1898	40	1899
	102	1901	20	1903	20	1905
	20	1909	20	1911		
1891	27	1896	20	1897	92	1898
	20	1899	20	1900	92	1901
	80	1903	16	1904	20	1906
	12	1907	20	1910	32	1911
1892	20	1898	40	1900	35	1901
	76	1903	43	1905	88	1906
	20	1907				
1893	175	1900	20	1901	15	1902
	59	1903	20	1904	15	1905
	20	1906	112	1907		

⅝-IN. WROUGHT-IRON SERVICES

Year Installed	Installed	In Service	Retired
1888	112	0	112
1942	0	0	0
TOTAL	112	0	112

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1888	20	1901	92	1912

¾-IN. WROUGHT-IRON SERVICES

Year Installed	Installed	In Service	Retired
1885	97	0	97
1886	310	0	310
1887	888	0	888
1888	1,907	0	1,907
1889	2,682	0	2,682
1890	2,381	0	2,381
1891	2,802	0	2,802
1892	2,289	0	2,289
1893	3,567	0	3,567
1894	46	0	46
1896	40	0	40
1898	130	0	130
1942	0	0	0
SUBTOTAL	17,139	0	17,139
Unknown	2,047	0	2,047
TOTAL	19,186	0	19,186

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1885	45	1890	20	1896	32	1900
1886	46	1886	49	1893	104	1894
	18	1895	24	1899	27	1900
	42	1903				
1887	7	1891	110	1894	20	1895
	56	1896	60	1897	72	1898
	111	1899	109	1900	150	1901
	82	1904	46	1905	45	1908
	20	1909				
1888	20	1890	44	1892	83	1893
	66	1894	130	1895	114	1896
	198	1898	237	1899	391	1900
	168	1901	46	1903	132	1904

¾-IN. WROUGHT-IRON SERVICES (contd.)

Retirements by Years (contd.)

Year Installed	Installed	In Service	Retired
1888	40 1905	46 1906	192 1907
1889	136 1894	124 1895	66 1896
	196 1897	112 1898	320 1899
	343 1800	209 1901	237 1902
	116 1903	129 1904	99 1905
	223 1906	184 1907	64 1908
	20 1909	38 1911	20 1922
	46 1927		
1890	92 1894	47 1896	92 1897
	154 1898	20 1899	388 1900
	514 1901	137 1902	244 1903
	94 1905	88 1906	258 1907
	207 1908	46 1914	
1891	35 1895	265 1896	193 1897
	46 1898	279 1899	619 1900
	257 1901	142 1902	168 1903
	20 1904	82 1905	284 1906
	92 1907	40 1908	112 1909
	18 1910	46 1912	58 1914
	46 1915		
1892	21 1895	39 1897	46 1898
	226 1899	452 1900	
	351 1901	219 1902	188 1903
	20 1904	66 1905	201 1906
	172 1907	106 1908	112 1909
	52 1910	18 1924	
1893	46 1896	67 1897	96 1898
	108 1899	419 1900	555 1901
	262 1902	209 1903	248 1904
	40 1905	426 1906	663 1907
	92 1908	142 1909	46 1910
	92 1914	10 1915	46 1926
1894	46 1903		
1896	40 1905		
1898	130 1904		

1-IN. WROUGHT-IRON SERVICES (contd.)

Year Installed	Installed	In Service	Retired
1892	343	0	343
1893	277	0	277
1896	20	0	20
1898	53	0	53
1942	0	0	0
SUBTOTAL	2,944	0	2,944
Unknown	1,165	0	1,165
TOTAL	4,109	0	4,109

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1884	97	1893	24	1897	47	1899
	107	1900	155	1901		
1885	47	1896	20	1898	29	1899
	180	1900	30	1901		
1886	27	1888	15	1895	136	1899
	46	1900	39	1905		
1887	36	1894	80	1902		
1888	46	1897	56	1901	18	1904
	109	1908				
1889	46	1896	66	1898	126	1900
	41	1901	46	1903	46	1904
	46	1906				
1890	50	1897	14	1900	46	1904
	46	1906	101	1908	50	1922
1891	98	1897	29	1901	29	1905
	27	1906				
1892	20	1898	98	1900	46	1901
	46	1902	113	1906	20	1908
1893	103	1899	128	1901	46	1907
1896	20	1903				
1898	53	1899				

1-IN. WROUGHT-IRON SERVICES

Year Installed	Installed	In Service	Retired
1884	430	0	430
1885	306	0	306
1886	263	0	263
1887	116	0	116
1888	229	0	229
1889	417	0	417
1890	307	0	307
1891	183	0	183

1¼-IN. WROUGHT-IRON SERVICES

Year Installed	Installed	In Service	Retired
1895	163	0	163
1942	0	0	0
TOTAL	163	0	163

Retirement by Years

Year Installed	Feet	Year
1895	163	1900

1½-IN. WROUGHT-IRON SERVICES

Year	Feet		
Installed	Installed	In Service	Retired
1886	45	0	45
1893	18	0	18
1895	183	0	183
1896	20	0	20
1942	0	0	0
SUBTOTAL	266	0	266
Unknown	20	0	20
TOTAL	286	0	286

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1886	45	1896				
1893	18	1899				
1895	136	1899	27	1912	20	1917
1896	20	1913				

2-IN. WROUGHT-IRON SERVICES

Year	Feet		
Installed	Installed	In Service	Retired
1884	211	0	211
1885	20	0	20
1886	24	0	24
1889	31	0	31
1890	49	0	49
1892	46	0	46
1893	46	0	46
1895	163	0	163
1900	15	0	15
1942	0	0	0
SUBTOTAL	605	0	605
Unknown	46	0	46
TOTAL	651	0	651

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1884	86	1898	102	1901	23	1908
1885	20	1897				
1886	24	1901				
1889	31	1896				
1890	49	1910				
1892	46	1906				
1893	46	1903				
1895	163	1909				
1900	15	1904				

2½-IN. WROUGHT-IRON SERVICES

Year	Feet		
Installed	Installed	In Service	Retired
1885	46	0	46
1895	20	0	20
1942	0	0	0
SUBTOTAL	66	0	66
Unknown	57	0	57
TOTAL	123	0	123

Retirements by Years

Year Installed	Feet	Year
1885	46	1898
1895	20	1908

3-IN. WROUGHT-IRON SERVICES

Year	Feet		
Installed	Installed	In Service	Retired
1885	133	0	133
1897	20	0	20
1942	0	0	0
TOTAL	153	0	153

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1885	105	1902	28	1906
1897	20	1931		

½-IN. COPPER SERVICES

Year	Feet		
Installed	Installed	In Service	Retired
1925	1,122	1,112	0
1926	14	14	0
1927	5,054	5,054	0
1928	8,095	8,095	0
1929	19,479	19,413	66
1930	14,455	14,337	118
1931	11,146	11,036	110
1932	6,591	6,405	186
1933	5,470	5,418	52
1934	3,597	3,477	120
1935	1,242	1,242	0
1936	727	727	0
1937	143	143	0
1938	48	48	0
1939	285	285	0

½-IN. COPPER SERVICES (contd.)

Year Installed	Installed	In Service	Retired
1940	58	58	0
1941	30	30	0
1942	0	0	0
SUBTOTAL	77,556	76,904	652
Unknown	69	69	0
TOTAL	77,625	76,973	652

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1929	52	1931	14	1941		
1930	14	1932	52	1933	52	1942
1931	40	1933	18	1939	52	1940
1932	18	1932	52	1933	96	1938
	20	1939				
1933	52	1933				
1934	104	1941	16	1942		

⅝-IN. COPPER SERVICES

Year Installed	Installed	In Service	Retired
1927	1,002	1,002	0
1928	3,880	3,834	46
1929	3,626	3,564	62
1930	2,120	2,120	0
1931	1,643	1,633	10
1932	996	996	0
1933	1,449	1,449	0
1934	1,690	1,676	14
1935	802	802	0
1936	122	122	0
1937	10	10	0
1938	158	158	0
1939	95	95	0
1940	66	66	0
1942	0	0	0
SUBTOTAL	17,659	17,527	132
Unknown	106	106	0
TOTAL	17,765	17,633	132

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1928	46	1941		
1929	46	1930	16	1939
1931	10	1936		
1934	14	1940		

¾-IN. COPPER SERVICES

Year Installed	Installed	In Service	Retired
1927	492	492	0
1928	1,017	933	84
1929	2,177	2,125	52
1930	1,643	1,643	0
1931	2,500	2,500	0
1932	1,242	1,192	50
1933	1,566	1,539	27
1934	1,359	1,343	16
1935	4,446	4,330	116
1936	7,627	7,565	62
1937	11,688	11,688	0
1938	11,440	11,440	0
1939	13,124	13,124	0
1940	18,171	18,171	0
1941	15,409	15,409	0
1942	0	0	0
SUBTOTAL	93,901	93,494	407
Unknown	74	74	0
TOTAL	93,975	93,568	407

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1928	14	1928	14	1929	56	1931
1929	52	1941				
1932	50	1938				
1933	27	1934				
1934	16	1942				
1935	116	1936				
1936	52	1936	10	1940		

1-IN. COPPER SERVICES

Year Installed	Installed	In Service	Retired
1927	379	359	20
1928	1,182	1,130	52
1929	2,142	2,142	0
1930	911	873	38
1931	1,130	1,114	16
1932	400	400	0
1933	594	582	12
1934	324	324	0
1935	429	429	0
1936	676	676	0
1937	591	425	166
1938	1,153	1,153	0
1939	2,556	2,556	0
1940	867	867	0
1941	1,498	1,498	0
1942	0	0	0
TOTAL	14,832	14,528	304

1-IN. COPPER SERVICES (contd.)

Retirements by Years

Year Installed	Feet	Year
1927	20	1939
1928	52	1929
1930	38	1936
1931	16	1939
1933	12	1940
1937	166	1939

1¼-IN. COPPER SERVICES

Year Installed	Feet		
	Installed	In Service	Retired
1938	24	24	0
1940	256	256	0
1941	64	64	0
1942	0	0	0
TOTAL	344	344	0

1½-IN. COPPER SERVICES

Year Installed	Feet		
	Installed	In Service	Retired
1935	131	131	0
1936	109	109	0
1937	58	58	0
1938	61	61	0
1939	134	134	0
1940	38	38	0
1941	62	62	0
1942	0	0	0
TOTAL	593	593	0

2-IN. COPPER SERVICES

Year Installed	Feet		
	Installed	In Service	Retired
1927	95	95	0
1928	249	249	0
1929	409	409	0
1930	297	297	0
1931	194	194	0
1932	147	147	0
1933	126	126	0
1934	166	166	0
1935	131	131	0
1936	72	72	0
1937	98	98	0
1938	76	76	0
1939	13	13	0
1940	108	108	0
1941	132	132	0
1942	0	0	0
TOTAL	2,313	2,313	0

3-IN. CAST-IRON SERVICES

Year Installed	Feet		
	Installed	In Service	Retired
1884	62	0	62
1895	16	0	16
1899	149	149	0
1900	205	98	107
1906	28	28	0
1942	0	0	0
TOTAL	460	275	185

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1884	16	1895	46	1902		
1895	16	1907				
1900	23	1912	52	1924	32	1939

4-IN. CAST-IRON SERVICES

Year Installed	Feet			Year Installed	Feet		
	Installed	In Service	Retired		Installed	In Service	Retired
1887	78	78	0	1903	111	111	0
1888	66	66	0	1904	544	485	59
1890	15	15	0	1905	228	172	56
1893	50	50	0	1906	553	431	122
1895	30	0	30	1907	468	468	0
1899	46	46	0	1908	436	436	0
1900	275	275	0	1909	705	705	0
1901	319	319	0	1910	897	878	19
1902	288	274	14	1911	74	74	0

4-IN. CAST-IRON SERVICES (contd.)

Year Installed	Feet Installed	In Service	Retired	Year Installed	Feet Installed	In Service	Retired
1912	1,461	1,376	85	1937	46	46	0
1913	558	558	0	1938	19	19	0
1914	501	501	0	1939	116	116	0
1915	380	380	0	1940	106	106	0
1916	235	235	0	1941	14	14	0
1917	165	165	0	1942	0	0	0
1918	117	117	0				
1919	283	283	0	SUBTOTAL	11,674	11,261	413
1920	261	247	14	Unknown	10	10	
1921	209	209	0				
1922	346	346	0	TOTAL	11,684	11,271	413
1923	14	14	0				
1924	252	252	0				
1925	42	28	14				
1926	212	212	0				
1927	219	219	0				
1928	91	91	0				
1929	210	210	0				
1930	256	256	0				
1931	150	150	0				
1932	126	126	0				
1933	23	23	0				
1934	15	15	0				
1935	64	64	0				

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1895	30	1903				
1902	14	1941				
1904	59	1937				
1905	56	1932				
1906	122	1933				
1910	19	1939				
1912	18	1934	53	1935	14	1941
1920	14	1935				
1925	14	1927				

6-IN. CAST-IRON SERVICES

Year Installed	Feet Installed	In Service	Retired	Year Installed	Feet Installed	In Service	Retired
1898	46	46	0	1926	470	470	0
1899	20	20	0	1927	167	167	0
1904	267	267	0	1928	446	446	0
1905	19	19	0	1929	180	180	0
1906	347	347	0	1930	351	351	0
1907	226	226	0	1931	288	288	0
1908	83	83	0	1932	114	114	0
1909	227	227	0	1933	152	152	0
1910	22	22	0	1934	145	145	0
1911	188	188	0	1935	304	304	0
1912	458	458	0	1936	60	60	0
1913	159	159	0	1937	83	83	0
1914	166	166	0	1938	57	57	0
1915	170	170	0	1939	393	393	0
1916	71	71	0	1940	228	228	0
1917	14	14	0	1941	55	55	0
1918	14	14	0	1942	0	0	0
1919	68	68	0				
1920	109	109	0	TOTAL	7,243	7,188	55
1921	22	22	0				
1922	105	105	0				
1923	373	373	0		*Retirements by Years*		
1924	281	226	55	Year Installed	Feet	Year	
1925	295	295	0	1924	55	1941	

8-IN. CAST-IRON SERVICES

Year Installed	Installed	In Service	Retired	Year Installed	Installed	In Service	Retired
1913	25	25	0	1929	208	208	0
1914	9	9	0	1931	12	12	0
1915	100	100	0	1939	55	55	0
1916	48	48	0	1940	20	20	0
1925	24	24	0	1942	0	0	0
1926	224	224	0		—	—	—
1928	14	14	0	TOTAL	739	739	0

½-IN. LEAD SERVICES

Year Installed	Installed	In Service	Retired	Year Installed	Installed	In Service	Retired
1894	3,750	1,426	2,324	1918	2,884	2,542	342
1895	3,793	1,322	2,471	1919	3,809	3,529	280
1896	2,490	1,184	1,306	1920	10,580	8,376	2,204
1897	2,145	823	1,322	1921	16,536	15,121	1,415
1898	1,683	668	1,015	1922	24,311	23,170	1,141
1899	5,994	1,629	4,365	1923	18,197	17,810	387
1900	9,536	3,142	6,394	1924	13,380	13,164	216
1901	7,671	2,419	5,252	1925	16,500	16,187	313
1902	1,494	1,203	291	1926	17,316	16,835	481
1903	29,393	23,713	5,680	1927	15,937	15,651	286
1904	29,297	23,975	5,322	1928	13,760	13,538	222
1905	52,802	40,861	11,941	1929	1,809	1,757	52
1906	55,825	43,984	11,841	1930	2,374	2,360	14
1907	40,588	35,303	5,285	1931	648	648	0
1908	19,823	17,337	2,486	1932	258	258	0
1909	29,899	27,016	2,883	1933	10	10	0
1910	36,883	31,741	5,142	1941	378	378	0
1911	42,394	37,329	5,065	1942	1,261	1,261	0
1912	47,150	43,576	3,574				
1913	38,440	34,064	4,376	SUBTOTAL	655,752	554,702	101,050
1914	23,929	20,038	3,891	Unknown	2,181	520	1,661
1915	5,296	4,912	384				
1916	2,568	1,988	580	TOTAL	657,933	555,222	102,711
1917	2,961	2,406	555				

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1894	58	1896	61	1898	101	1899	1895	66	1900	76	1901	150	1902
	6	1900	17	1901	20	1903		53	1905	20	1907	31	1908
	36	1904	77	1905	80	1906		80	1910	20	1911	224	1912
	46	1907	149	1908	112	1909		46	1913	273	1914	46	1915
	59	1910	46	1911	47	1913		46	1916	20	1917	21	1918
	20	1915	16	1916	32	1917		92	1919	132	1920	96	1921
	95	1918	20	1920	132	1922		20	1922	170	1923	20	1924
	46	1923	86	1924	46	1925		46	1925	17	1926	80	1927
	40	1926	46	1927	149	1928		92	1929	67	1933	46	1934
	20	1929	46	1930	63	1932		46	1935	20	1936	46	1937
	227	1933	46	1936	65	1937		46	1938	186	1939	46	1940
	46	1938	105	1939					31	1941				

½-IN. LEAD SERVICES (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1896	47	1904	80	1905	195	1906	1901	176	1914	110	1915	320	1916
	71	1907	7	1908	46	1910		370	1917	136	1918	156	1919
	46	1918	20	1920	102	1921		193	1920	191	1921	98	1922
	46	1923	66	1924	32	1925		159	1923	152	1924	202	1925
	40	1927	98	1929	134	1930		80	1926	46	1927	10	1928
	58	1931	20	1932	27	1933		124	1929	14	1930	66	1931
	20	1934	77	1936	20	1939		56	1932	74	1933	56	1935
	34	1940	20	1941				52	1936	98	1937	67	1938
1897	69	1900	58	1903	48	1905		164	1939	44	1940		
	70	1906	47	1911	46	1912	1902	25	1907	66	1918	10	1920
	127	1913	46	1914	20	1916		20	1921	104	1926	20	1933
	85	1919	20	1925	66	1926		18	1935	14	1939	14	1940
	395	1927	20	1929	20	1937	1903	56	1903	92	1906	14	1909
	66	1938	119	1939				166	1910	196	1911	139	1912
1898	136	1899	15	1901	60	1904		444	1913	98	1914	138	1917
	111	1906	26	1912	37	1913		14	1918	144	1919	276	1920
	66	1914	70	1919	66	1920		286	1921	162	1922	94	1923
	46	1922	46	1924	86	1926		92	1924	146	1925	126	1926
	20	1928	70	1930	37	1934		186	1927	110	1928	82	1929
	20	1935	43	1936	20	1937		171	1930	90	1931	88	1932
	20	1939	20	1942				136	1933	196	1934	258	1935
1899	36	1900	36	1901	36	1902		341	1936	210	1937	258	1938
	126	1903	52	1904	184	1905		266	1939	232	1940	160	1941
	83	1906	164	1907	294	1908		213	1942				
	224	1909	215	1910	140	1911	1904	16	1905	32	1906	46	1907
	246	1912	72	1913	113	1914		46	1908	61	1910	80	1911
	217	1915	46	1916	67	1918		174	1912	488	1913	124	1914
	166	1919	274	1920	50	1921		28	1915	48	1916	14	1917
	66	1922	138	1923	98	1924		20	1918	63	1919	152	1920
	46	1925	154	1926	106	1927		114	1921	80	1922	134	1924
	36	1928	20	1929	212	1930		136	1925	98	1926	222	1927
	52	1931	14	1933	14	1935		66	1928	146	1929	92	1930
	26	1937	124	1938	188	1940		256	1931	131	1932	342	1933
	63	1941	32	1942				136	1934	220	1935	106	1936
1900	66	1900	76	1901	150	1902		414	1937	92	1938	454	1939
	133	1905	220	1906	268	1907		201	1940	246	1941	244	1942
	214	1908	298	1909	245	1910	1905	24	1905	60	1906	153	1907
	24	1911	217	1912	338	1913		74	1908	73	1909	62	1910
	151	1914	94	1915	64	1916		248	1911	205	1912	497	1913
	306	1917	266	1918	216	1919		272	1914	313	1915	74	1916
	214	1920	147	1921	209	1922		14	1917	48	1918	26	1919
	232	1923	304	1924	86	1925		439	1920	345	1921	184	1922
	230	1926	285	1927	159	1928		387	1923	86	1924	385	1925
	24	1929	182	1930	52	1931		310	1926	258	1927	430	1928
	54	1932	74	1933	69	1934		476	1929	390	1930	624	1931
	160	1936	249	1937	80	1938		263	1932	340	1933	504	1934
	98	1939	66	1940	60	1941		208	1935	438	1936	563	1937
	14	1942						563	1937	564	1938	656	1939
1901	20	1901	29	1903	10	1904		532	1940	979	1941	437	1942
	65	1905	315	1906	172	1907	1906	52	1906	106	1907	114	1908
	358	1908	320	1909	140	1910		106	1909	399	1910	269	1911
	164	1911	274	1912	171	1913		163	1912	264	1913	169	1914

½-IN. LEAD SERVICES (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year
1906	221	1915	150	1916	41	1917
	60	1918	114	1919	419	1920
	315	1921	206	1922	258	1923
	428	1924	407	1925	302	1926
	279	1927	387	1928	313	1929
	352	1930	609	1931	354	1932
	283	1933	196	1934	309	1935
	623	1936	541	1937	677	1938
	762	1939	373	1940	880	1941
	340	1942				
1907	16	1907	46	1910	55	1911
	97	1912	196	1913	66	1914
	14	1915	24	1916	155	1917
	46	1918	96	1919	217	1920
	206	1921	139	1922	94	1923
	88	1924	74	1925	40	1926
	163	1927	45	1928	246	1929
	60	1930	121	1931	154	1932
	123	1933	274	1934	369	1935
	350	1936	323	1937	160	1938
	295	1939	312	1940	369	1941
	252	1942				
1908	12	1908	14	1909	40	1910
	16	1911	147	1912	52	1913
	60	1914	92	1918	46	1919
	20	1920	25	1921	52	1922
	37	1923	55	1924	14	1925
	14	1927	100	1928	60	1929
	76	1930	76	1931	97	1932
	127	1933	14	1934	52	1935
	144	1936	86	1937	140	1938
	266	1939	245	1940	203	1941
	104	1942				
1909	80	1911	34	1912	60	1913
	52	1914	153	1915	72	1916
	104	1917	79	1918	65	1919
	52	1920	66	1921	34	1922
	14	1923	14	1925	88	1926
	50	1927	66	1928	132	1929
	184	1930	80	1931	54	1932
	64	1933	106	1934	52	1935
	64	1936	76	1937	118	1938
	330	1939	100	1940	166	1941
	274	1942				
1910	52	1911	260	1912	52	1913
	130	1914	47	1915	54	1917
	12	1919	92	1920	50	1921
	132	1922	14	1923	83	1924
	161	1925	191	1926	94	1927
	156	1928	63	1929	114	1930
	238	1931	66	1932	88	1933

Year Installed	Feet	Year	Feet	Year	Feet	Year
1910	152	1934	50	1935	282	1936
	662	1937	466	1938	413	1939
	354	1940	458	1941	156	1942
1911	74	1911	341	1912	35	1913
	80	1914	12	1915	40	1916
	40	1917	46	1918	34	1919
	165	1920	157	1921	168	1922
	161	1923	128	1924	10	1926
	40	1927	52	1928	52	1929
	114	1930	88	1931	164	1932
	264	1933	292	1934	82	1935
	264	1936	452	1937	338	1938
	290	1939	354	1940	578	1941
	150	1942				
1912	102	1913	40	1914	68	1915
	50	1916	40	1918	14	1919
	163	1920	34	1921	49	1922
	168	1923	24	1924	38	1926
	160	1928	90	1929	265	1930
	10	1931	99	1932	190	1933
	66	1934	367	1935	70	1936
	126	1937	311	1938	176	1939
	386	1940	312	1941	156	1942
1913	126	1913	14	1916	14	1919
	66	1920	127	1922	83	1923
	140	1924	358	1925	24	1926
	126	1927	128	1928	252	1929
	134	1930	196	1931	198	1932
	268	1933	144	1934	140	1935
	270	1936	241	1937	106	1938
	204	1939	462	1940	373	1941
	182	1942				
1914	40	1914	52	1915	50	1916
	43	1917	50	1918	118	1919
	136	1920	190	1921	252	1922
	75	1923	36	1924	12	1925
	132	1927	40	1928	114	1929
	149	1930	42	1931	174	1932
	116	1933	330	1934	80	1935
	254	1936	426	1937	286	1938
	112	1939	158	1940	292	1941
	132	1942				
1915	29	1915	14	1926	20	1927
	78	1928	24	1929	79	1930
	14	1938	14	1939	60	1940
	52	1941				
1916	52	1918	46	1920	46	1921
	14	1924	46	1925	63	1930
	16	1932	77	1934	50	1935
	14	1937	18	1938	52	1936
	14	1941	72	1942		

½-in. Lead Services (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1917	104	1920	60	1922	46	1923	1922	62	1923	26	1928	64	1929
	46	1926	52	1928	66	1929		107	1930	93	1931	104	1932
	7	1934	14	1936	56	1939		74	1934	175	1937	96	1938
	52	1940	52	1941				165	1939	116	1940	59	1941
1918	52	1921	52	1923	46	1924	1923	46	1926	46	1929	14	1930
	46	1926	14	1933	28	1936		12	1933	52	1934	34	1937
	28	1939	16	1940	60	1942		66	1939	52	1940	23	1941
1919	14	1920	10	1922	14	1929		42	1942				
	34	1930	50	1935	14	1936	1924	52	1934	52	1935	32	1937
	14	1938	66	1939	66	1941		14	1938	52	1939	14	1940
1920	21	1921	52	1922	37	1923	1925	20	1927	25	1929	48	1930
	52	1924	89	1925	104	1926		20	1931	52	1937	52	1938
	104	1928	72	1929	215	1930		82	1939	14	1940		
	36	1931	52	1932	170	1933	1926	72	1928	52	1929	14	1931
	46	1934	62	1935	126	1936		14	1936	60	1937	41	1939
	180	1937	429	1938	72	1939		80	1940	128	1941	20	1942
	104	1940	64	1941	117	1942	1927	28	1933	52	1935	156	1937
1921	66	1923	14	1924	46	1926		14	1939	36	1940		
	97	1928	126	1929	28	1930	1928	128	1932	52	1935	14	1937
	52	1931	52	1932	28	1933		14	1939	14	1941		
	52	1935	156	1936	156	1937	1929	52	1929				
	52	1938	222	1939	112	1940	1930	14	1942				
	156	1941											

¾-in. Lead Services

Year Installed	Feet Installed	Feet In Service	Feet Retired	Year Installed	Feet Installed	Feet In Service	Feet Retired
1895	160	160	0	1919	830	750	80
1898	77	31	46	1920	2,832	2,663	169
1899	1,253	678	575	1921	2,688	2,477	211
1900	4,191	2,574	1,617	1922	3,271	2,802	469
1901	6,207	4,129	2,078	1923	2,341	2,275	66
1902	17,730	11,683	6,047	1924	2,252	2,238	14
1903	7,723	5,470	2,253	1925	2,058	2,037	21
1904	14,203	12,362	1,841	1926	2,344	2,258	86
1905	29,551	25,685	3,866	1927	3,004	3,004	0
1906	26,121	21,117	5,004	1928	1,003	933	70
1907	15,676	12,642	3,034	1929	942	942	0
1908	15,847	14,461	1,386	1930	204	204	0
1909	12,745	10,531	2,214	1931	255	255	0
1910	14,966	12,855	2,111	1939	112	112	0
1911	18,301	17,301	1,000	1941	438	438	0
1912	20,035	18,327	1,708	1942	656	604	52
1913	17,351	14,980	2,371				
1914	10,003	9,065	938	SUBTOTAL	259,905	220,460	39,445
1915	1,056	1,004	52	Unknown	698	96	602
1916	464	412	52				
1917	513	499	14	TOTAL	260,603	220,556	40,047
1918	502	502	0				

⅝-IN. LEAD SERVICES (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1898	46	1940				
1899	60	1905	33	1913	68	1914
	14	1917	46	1920	20	1921
	14	1922	20	1923	52	1929
	46	1932	20	1933	68	1935
	18	1939	82	1940	14	1942
1900	75	1900	40	1905	29	1906
	20	1907	78	1910	52	1913
	46	1914	14	1918	46	1919
	154	1920	66	1921	14	1924
	12	1926	52	1927	95	1928
	150	1929	100	1930	119	1931
	46	1935	68	1936	102	1937
	66	1938	41	1939	46	1940
	86	1941				
1901	52	1901	66	1903	20	1905
	66	1906	98	1907	39	1908
	34	1910	154	1911	208	1913
	25	1914	65	1915	30	1916
	40	1917	138	1919	64	1921
	143	1922	59	1924	52	1926
	10	1927	65	1928	25	1930
	69	1931	46	1932	40	1933
	72	1936	52	1938	86	1939
	46	1940	52	1941	162	1942
1902	59	1903	82	1906	203	1907
	128	1908	14	1910	136	1911
	20	1912	351	1913	184	1914
	42	1915	106	1916	12	1917
	108	1918	120	1919	164	1920
	155	1921	127	1922	208	1923
	14	1924	206	1925	112	1926
	188	1927	286	1928	256	1929
	48	1930	148	1931	310	1932
	83	1933	268	1934	104	1935
	294	1936	124	1937	462	1938
	350	1939	261	1940	104	1941
	210	1942				
1903	60	1906	84	1908	62	1910
	14	1913	14	1917	56	1919
	156	1920	52	1921	14	1923
	123	1924	52	1925	152	1926
	108	1927	170	1928	216	1929
	122	1931	52	1932	196	1933
	60	1934	60	1935	20	1937
	30	1938	180	1939	80	1940
	120	1942				
1904	46	1907	79	1909	52	1911
	14	1912	66	1913	72	1915
	52	1919	24	1920	80	1921
	156	1924	36	1925	95	1927
	58	1928	14	1929	66	1931
	52	1932	103	1934	52	1935

Year Installed	Feet	Year	Feet	Year	Feet	Year
1904	184	1936	52	1937	88	1938
	170	1939	66	1940	150	1941
	14	1942				
1905	14	1905	14	1907	12	1909
	50	1912	316	1913	70	1914
	52	1915	18	1918	8	1919
	118	1920	173	1921	97	1922
	86	1924	183	1925	89	1928
	84	1929	144	1930	186	1931
	94	1932	88	1933	208	1934
	217	1935	242	1936	278	1937
	214	1938	246	1939	48	1940
	375	1941	147	1942		
1906	74	1909	48	1910	77	1911
	182	1912	52	1913	29	1914
	68	1916	100	1917	52	1918
	80	1919	122	1920	118	1921
	125	1922	104	1923	54	1924
	104	1925	167	1926	129	1927
	173	1928	117	1929	301	1930
	246	1931	156	1932	313	1933
	222	1934	156	1935	244	1936
	138	1937	176	1938	501	1939
	158	1940	366	1941	52	1942
1907	14	1910	109	1911	66	1912
	28	1913	14	1914	14	1915
	106	1918	20	1919	121	1920
	52	1921	114	1922	66	1923
	237	1924	142	1925	92	1927
	14	1928	167	1929	52	1930
	220	1931	92	1932	108	1934
	104	1935	105	1936	88	1937
	138	1938	160	1939	352	1940
	198	1941	41	1942		
1908	24	1912	52	1916	12	1918
	52	1919	38	1920	14	1921
	130	1922	46	1923	52	1924
	89	1929	10	1930	14	1931
	46	1932	97	1933	52	1934
	156	1936	96	1937	52	1938
	68	1940	178	1941	108	1942
1909	52	1912	24	1913	52	1914
	14	1915	81	1918	14	1919
	72	1920	118	1922	150	1923
	62	1924	106	1926	143	1929
	66	1931	14	1932	138	1933
	52	1934	66	1935	150	1936
	232	1937	152	1938	52	1939
	158	1940	80	1941	166	1942
1910	130	1912	10	1913	52	1917
	95	1919	8	1920	14	1922
	66	1924	50	1926	20	1927
	118	1930	98	1931	40	1933

½-IN. LEAD SERVICES (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1910	86	1934	96	1935	60	1936	1913	343	1941	52	1942		
	178	1937	66	1938	112	1939	1914	24	1917	52	1921	53	1922
	208	1940	500	1941	104	1942		52	1929	52	1930	91	1931
1911	10	1912	52	1915	66	1920		46	1933	52	1934	60	1935
	42	1922	92	1923	38	1925		152	1936	152	1937	14	1938
	24	1929	14	1930	14	1932		52	1940	12	1941	74	1942
	40	1936	52	1937	14	1939	1915	52	1942				
	168	1940	374	1941			1916	52	1919				
1912	14	1914	52	1916	60	1917	1917	14	1921				
	12	1919	229	1920	52	1922	1919	52	1921	10	1935	18	1940
	44	1923	40	1924	30	1925	1920	14	1922	14	1929	35	1931
	52	1926	11	1927	24	1928		54	1934	52	1937		
	102	1929	14	1930	118	1932	1921	14	1926	47	1933	52	1936
	126	1933	106	1934	60	1935		46	1940	52	1941		
	102	1936	102	1937	170	1938	1922	20	1923	136	1929	15	1930
	66	1939	42	1940	14	1941		32	1934	18	1935	52	1936
	66	1942						138	1938	58	1939		
1913	52	1920	156	1923	70	1924	1923	14	1930	52	1931		
	104	1925	52	1926	46	1928	1924	14	1934				
	52	1929	118	1930	90	1931	1925	21	1937				
	46	1932	96	1933	66	1934	1926	52	1930	20	1938	14	1942
	106	1935	104	1936	196	1937	1928	56	1931	14	1941		
	196	1938	172	1939	254	1940	1942	52	1942				

¼-IN. LEAD SERVICES

Year Installed	Feet Installed	In Service	Retired	Year Installed	Feet Installed	In Service	Retired
1894	1,560	806	754	1917	484	377	107
1895	2,741	1,103	1,638	1918	1,044	942	102
1896	1,818	1,177	641	1919	760	657	103
1897	1,663	865	798	1920	1,654	1,408	246
1898	1,453	753	700	1921	1,512	1,345	167
1899	2,628	2,035	593	1922	2,203	2,151	52
1900	1,675	850	825	1923	1,506	1,322	184
1901	2,065	1,102	963	1924	1,427	1,151	276
1902	4,049	2,992	1,057	1925	1,654	1,541	113
1903	5,357	4,065	1,292	1926	1,541	1,423	118
1904	5,462	4,589	873	1927	1,304	1,264	40
1905	5,137	3,689	1,448	1928	1,293	1,279	14
1906	10,827	9,170	1,657	1929	1,952	1,938	14
1907	3,670	2,691	979	1930	672	672	0
1908	3,162	2,564	598	1931	342	316	26
1909	4,136	3,042	1,094	1932	76	76	0
1910	3,745	3,010	735	1939	66	66	0
1911	3,690	3,166	524	1942	9,452	9,452	0
1912	5,210	3,779	1,431				
1913	4,041	3,433	608	SUBTOTAL	107,737	86,571	21,166
1914	3,164	2,824	340	Unknown	1,560	332	1,228
1915	1,039	1,001	38				
1916	503	485	18	TOTAL	109,297	86,903	22,394

½-IN. LEAD SERVICES (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1894	20	1899	20	1906	46	1907
	15	1908	15	1914	130	1921
	66	1922	120	1924	20	1926
	46	1928	106	1929	46	1936
	104	1939				
1895	62	1898	20	1900	114	1906
	39	1910	48	1912	20	1916
	66	1920	149	1922	19	1924
	52	1925	46	1928	228	1929
	46	1930	225	1932	46	1933
	20	1934	46	1935	282	1937
	64	1939	46	1940		
1896	46	1907	117	1908	46	1917
	32	1920	144	1921	46	1930
	14	1936	112	1939	17	1940
	46	1941	21	1942		
1897	46	1902	7	1908	105	1913
	135	1919	16	1921	20	1922
	46	1923	34	1926	97	1930
	20	1932	20	1933	100	1936
	86	1939	46	1940	20	1941
1898	50	1902	67	1905	14	1906
	197	1908	40	1910	20	1911
	42	1913	18	1914	138	1920
	20	1921	22	1930	46	1931
	26	1936				
1899	14	1904	26	1914	12	1915
	46	1922	52	1923	52	1925
	52	1926	56	1929	52	1930
	69	1931	52	1936	20	1937
	60	1941	30	1942		
1900	46	1901	24	1903	20	1904
	154	1908	20	1910	73	1915
	20	1919	14	1921	10	1924
	42	1926	20	1927	66	1930
	12	1933	46	1935	7	1936
	99	1939	152	1940		
1901	32	1903	97	1908	70	1910
	33	1912	120	1913	29	1915
	30	1916	20	1917	15	1918
	114	1919	55	1920	15	1921
	62	1924	56	1926	97	1939
	14	1940	104	1941		
1902	112	1903	48	1905	14	1908
	46	1911	116	1913	14	1914
	24	1915	50	1922	46	1923
	24	1927	84	1928	59	1929
	14	1930	24	1932	66	1933
	20	1934	78	1935	52	1936
	30	1937	47	1938	31	1939
	14	1941	44	1942		
1903	28	1905	53	1908	52	1911
	72	1912	128	1913	66	1914

Year Installed	Feet	Year	Feet	Year	Feet	Year
1903	29	1921	74	1922	56	1924
	42	1925	18	1926	32	1927
	14	1928	42	1929	142	1930
	14	1931	14	1934	78	1936
	120	1937	46	1939	126	1940
	46	1941				
1904	46	1905	26	1907	25	1908
	46	1910	52	1913	76	1914
	20	1920	20	1921	52	1922
	46	1926	14	1929	76	1931
	14	1932	40	1934	104	1935
	46	1937	36	1938	48	1939
	52	1940	14	1941	20	1942
1905	40	1908	44	1910	66	1911
	27	1912	52	1913	24	1915
	98	1917	12	1918	66	1920
	20	1921	104	1922	52	1926
	36	1928	100	1929	88	1930
	14	1931	42	1932	54	1933
	38	1934	14	1935	151	1936
	70	1938	110	1939	106	1940
	20	1941				
1906	46	1906	27	1910	27	1911
	49	1912	56	1914	41	1917
	82	1919	46	1920	45	1921
	23	1925	80	1926	30	1927
	83	1928	46	1929	67	1930
	54	1931	27	1932	173	1933
	66	1934	25	1935	56	1936
	166	1939	96	1940	32	1941
	214	1942				
1907	140	1913	46	1916	52	1918
	12	1920	31	1921	56	1922
	45	1925	52	1932	52	1933
	52	1934	46	1935	52	1936
	56	1937	175	1939	52	1940
	60	1941				
1908	20	1909	108	1911	14	1912
	62	1913	58	1915	37	1916
	25	1929	104	1935	14	1938
	104	1939	52	1940		
1909	42	1911	52	1912	124	1913
	54	1914	82	1919	52	1921
	62	1929	14	1930	52	1931
	52	1936	66	1937	168	1938
	50	1939	196	1940	28	1941
1910	37	1912	64	1913	60	1926
	110	1928	28	1929	14	1932
	98	1934	96	1936	88	1938
	20	1939	14	1940	156	1941
1911	52	1916	16	1917	20	1921
	52	1924	36	1930	52	1935
	52	1936	52	1937	126	1938

¾-IN. LEAD SERVICES (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year		Year Installed	Feet	Year	Feet	Year	Feet	Year
1911	52	1939	14	1940				1917	20	1918	46	1935	41	1937
1912	46	1914	27	1916	52	1918		1918	50	1929	52	1941		
	52	1919	90	1922	14	1924		1919	20	1921	83	1941		
	46	1925	14	1927	46	1928		1920	52	1922	14	1926	62	1929
	137	1929	46	1931	66	1932			66	1940	52	1941		
	14	1934	52	1936	104	1937		1921	129	1936	38	1939		
	193	1938	54	1939	222	1940		1922	52	1942				
	104	1941	52	1942				1923	14	1926	52	1935	118	1941
1913	42	1924	14	1928	52	1931		1924	82	1930	90	1939	104	1941
	88	1933	52	1934	156	1936		1925	52	1937	9	1939	52	1941
	86	1937	52	1939	52	1940		1926	52	1936	14	1940	52	1941
	14	1942						1927	26	1931	14	1939		
1914	26	1915	46	1927	14	1928		1928	14	1940				
	104	1936	52	1938	98	1940		1929	14	1941				
1915	14	1926	24	1931				1931	26	1937				
1916	18	1938												

1-IN. LEAD SERVICES

Year Installed	Installed	In Service	Retired		Year Installed	Installed	In Service	Retired
1897	90	20	70		1919	1,292	1,137	155
1898	20	0	20		1920	1,199	990	209
1899	130	78	52		1921	885	743	142
1900	455	455	0		1922	928	669	259
1901	387	236	151		1923	630	520	110
1902	462	388	74		1924	1,075	818	257
1903	212	152	60		1925	848	727	121
1904	791	573	218		1926	1,655	1,655	0
1905	2,218	2,037	181		1927	1,136	1,070	66
1906	2,648	2,200	448		1928	1,192	1,192	0
1907	1,534	1,292	242		1929	1,111	1,111	0
1908	1,378	952	426		1930	334	334	0
1909	2,491	2,402	89		1932	14	14	0
1910	3,191	2,872	319		1933	26	26	0
1911	4,117	3,728	389		1939	15	15	0
1912	5,659	5,144	515		1942	0	0	0
1913	4,169	3,824	345					
1914	5,134	4,832	302		SUBTOTAL	51,054	45,300	5,754
1915	860	860	0		Unknown	357	46	311
1916	801	693	108					
1917	975	755	220		TOTAL	51,411	45,346	6,065
1918	992	786	206					

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year		Year Installed	Feet	Year	Feet	Year	Feet	Year
1897	70	1915						1902	20	1906	54	1933		
1898	20	1935						1903	46	1909	14	1926		
1899	52	1928						1904	98	1909	14	1927	46	1932
1901	46	1903	105	1908					14	1935	46	1940		

Year 1924 1927 1930 1936 1940 1908 1914 1922 1931 1935 1939 1942 1911 1915 1920 1926 1930 1933 1936 1940 1911 1917 1921 1927 1930 1933 1936 1941 1918 1922 1933 1936 1940 1912 1916 1938 1913 1921 1931 1938 1941 1926 1932 1938 1941 1921 1935 1938

1-in. Lead Services (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year
1905	40	1907	15	1922	14	1928
	20	1929	46	1936	12	1937
	34	1939				
1906	15	1912	28	1913	15	1925
	16	1927	66	1929	78	1932
	40	1933	104	1934	20	1935
	20	1936	46	1938		
1907	58	1913	14	1927	31	1928
	20	1930	39	1937	80	1940
1908	30	1913	54	1920	46	1923
	24	1925	81	1928	44	1929
	114	1930	33	1939		
1909	24	1926	13	1927	52	1934
1910	52	1910	48	1913	14	1919
	10	1921	15	1924	58	1929
	60	1937	58	1940	14	1941
1911	14	1917	10	1928	75	1934
	16	1939	118	1940	156	1941
1912	33	1914	43	1920	40	1924
	21	1926	46	1933	16	1935
	52	1938	62	1940	202	1941
1913	20	1914	21	1922	14	1924
	40	1931	44	1936	46	1939
	28	1940	132	1941		
1914	12	1917	14	1927	52	1931
	14	1934	14	1937	14	1938
	40	1939	10	1940	132	1941
1916	108	1940				
1917	36	1920	132	1926	52	1940
1918	59	1929	104	1935	43	1939
1919	28	1922	63	1936	46	1940
	18	1941				
1920	144	1930	14	1934	28	1936
	23	1939				
1921	14	1928	52	1931	76	1936
1922	186	1933	38	1935	21	1936
	14	1942				
1923	24	1928	86	1941		
1924	108	1937	129	1939	20	1941
1925	54	1927	15	1935	52	1941
1927	14	1927	52	1941		

1½-in. Lead Services

Year Installed	Feet Installed	Feet In Service	Feet Retired	Retirements by Years — Year Installed	Feet	Year
1899	18	0	18	1899	18	1939
1910	104	104	0			
1942	0	0	0			
Total	122	104	18			

2-in. Lead Services

Year Installed	Feet Installed	Feet In Service	Feet Retired	Retirements by Years — Year Installed	Feet	Year
1895	21	0	21	1895	21	1919
1906	116	70	46	1906	46	1928
1917	48	48	0	1918	10	1935
1918	24	14	10			
1919	160	160	0			
1931	52	52	0			
1942	0	0	0			
Total	421	344	77			

ol. 37

Year
1924
1939

1931
1938
1941

1940
1939
1940

1936

1936
1936

1941
1941

Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **34**: 412 (Mar. '42) indicates volume 34, page 412, issue dated March 1942. If the publication is paged by the issue, **34**: 3: 56 (Mar. '42) indicates volume 34, number 3, page 56, issue dated March 1942. Initials following an abstract indicate reproduction, by permission, from periodicals, as follows: *B.H.—Bulletin of Hygiene (British); C.A.—Chemical Abstracts; P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research (British); I.M.—Institute of Metals (British).*

BOILERS, FUEL AND FEEDWATER

The Combating of Boiler Scale in Cooling Units Having Recirculated Water Supplies. G. E. KRUSHEL. Vodosnabzhenie i Sanit. Tekh. (U.S.S.R.) **16**: 5: 29 ('41); Chem. Zentr. (Ger.) **II**: 1832 ('42). Formation of inorg. boiler scale in closed cooling systems can be prevented by drawing off portion of circulating water or by chem. treatment of added water. Former method effective only when added water carries temporary hardness of 4-11°. Added water can be treated to prevent decompn. of bicarbonates or to reduce bicarbonate hardness of evapg. water to <12°. Methods used for this purpose: (1) addn. of Na hexametaphosphate (this method used in America but according to Russian investigations deposition of $CaCO_3$ not entirely prevented by use of small amts. of reagent); (2) satn. of circulating water with CO_2 to maint. state of equil.; (3) treatment of added water with HCl to convert bicarbonates into chlorides; (4) softening added water in cation-exchange filters; (5) addn. of lime to added water with subsequent filtration to remove bicarbonates; and (6) conversion of bicarbonates in added water into sulfates by addn. of H_2SO_4. Last method especially expedient, since consumption of addnl. water only 2.6 or 4.6% of circulating water, depending on type of cooling unit. This an advantage even when scale formation can be prevented by drawing off portion of water as, e.g., in regions where water supply not abundant. Deposition of gypsum need not be feared, since such deposition would be possible only for water having improbably high gypsum hardness of 35-40°. Amt. of H_2SO_4 used must be such that certain residual alky. remains so that attack of metal and concrete avoided. Methods 3 and 4 also proved satisfactory.—*C.A.*

Determining Amounts of Contaminated Material Entering Boilers. B. C. SPRAGUE. Combustion **16**: 1: 45 ('44). Measure of contaminating impurities entering boiler can be had from relation of concns. of components of treating chems. and of impurities remaining in soln. in boiler water. Simple expression is offered to illustrate this method. Measure based on principle that, to extent that various chem. components added to boiler water remain in soln., their concns. in feedwater will have same relation to each other as amts. added. Where phosphate treatment employed, measure of contamn. can probably most conveniently be based on concns. of PO_4 and SO_4 in boiler water. Since phosphate treatment prevents pptn. of sulfates, all of sulfate in impurities remains in soln. in boiler water. Some of phosphate added enters into combination with Ca and Mg salts getting into feedwater with impurities and is pptd. from soln., leaving in soln. uncombined phosphate. Knowledge of hardness and SO_4 concn. of raw water makes it possible to adjust for quant. of phosphate which will be elimd. in pptg. Ca and Mg salts. In order to minimize effect of treatment added to boilers on filling, SO_4 and PO_4 concns. in boiler water should be based on avgs. from boilers that have been in service some time since refilling.—*C.A.*

The Removal of Silica From Boiler Water. W. F. GERRARD. Power & Works Engr. (Br.) **38**: 281 ('43). Effects of silica in boiler water and methods for its removal from water described. Methods for removing silica may be divided into 3 classes: those in which chems., added to softened water, combine with residual calcium and so prevent formation of calcium silicate which produces scale; those in

which silica adsorbed by coagulants added with chems. used for softening; and those in which silica pptd. In third class of methods insoluble silica compd. removed by filters in softening plant. In B.P. 527,153 use of magnesium oxide and barium hydroxide for softening water and for removing silica described. Further work has shown that removal of silica by magnesium oxide affected by commercial grade of magnesium oxide used, by temp., and by intimacy and period of contact of reagent with water. Method of application of magnesium oxide to boiler water described in B.P. 542,751 now in use on large scale and known as "M.W." process. Magnesium oxide added to softened water to remove silica also removes permanent hardness remaining in water; also reacts with carbon dioxide and maints. pH value of boiler water above 9.4. Old deposits in boilers often disintegrate after water treated for few months by this process.—*W.P.R.*

Use of Electrophotometric Methods for Analysis of Raw, Treated and Boiler Waters, Boiler Scale and Boiler Sludge. H. M. LAUDEMANN ET AL. Am. Ry. Engr. Assn. **45:** 441: 52 (Nov. '43). Investigation indicates that development of these methods not yet reached stage where suitable standardized procedures can be recommended. Types of equip. in use described briefly.—*R. C. Bardwell.*

Modern Water Purification for High-Pressure Boilers in Industrial Plants. E. PFLEIDERER. Chem.-Ztg. (Ger.) **68:** 56 ('44). For boiler water, prelim. treatment with CaO followed by phosphate treatment. After settling and filtering, water treated with SO_2 to remove traces of O. With turbines, difficulties encountered owing to pptn. of SiO_2. Removed by addns. of MgO and CaO. Use of $Mg(OH)_2$ leads to better floc. Residual hardness removed with nonsiliceous exchange substance (Wofatit). Flow sheets included and use of complete demineralization with exchange substances noted.—*C.A.*

Inhibitors for Acid Washes to Remove Boiler Scale. A. P. MAMET. Tekstil. Prom. (U.S.S.R.) **4:** 7: 25 ('44). More than 40 substances tested for eff. in protecting metal parts when boilers and similar installations acid-treated to remove scale. Inhibiting effect (τ) measured by percentage by which inhibitor decreases loss in wt. of metal treated in given acid in g. per sq.m. per hr. High τ due to

presence of certain polar groups. Of these most effective are N- and S-contg. heterocycles, and CHO group; NH_2 and azo groups less effective; OH, CO_2H and SO_3H, still less so, τ increases with increase in molecular wt. of compd. and number of polar groups. For most effective inhibitors tested, added in quants. of 2–10 g./l. to 10% HCl (cold), τ 85–99%. In decreasing order of their effectiveness they were urotropine (I), formalin (II), Unicol (vegetable extract) (III), quinoline (IV), furfural and joiners glue (V). Inhibiting action specific and depends on acid and temp. I and II most effective in cold 10% HCl (τ = 94%). In cold 5% H_2SO_4 IV (τ = 96%) and NH_4CNS most effective. In cold 10% $H_3PO_4NH_4CNS$ (τ = 98%) and V (τ = 96%) most effective. For HCl + HF I and II gave best results. In HCl (concn. 2–10%) τ diminishes with increase in concn. of acid; in H_3PO_4 it increases; while in H_2SO_4 (concn. 0.5–5%) not affected significantly. Increase in temp. generally lowers τ. When added in sufficient quants. τ of V remained const. for rising temps. up to 100° in all acids except H_3PO_4. For III τ declines sharply at temps. above 60–70°. In HCl and HCl + HF I and II remain almost unaffected by temp. Furfural strongly affected by temp. Generally at elevated temps. H_3PO_4 hardest to inhibit, while HF and HCl + HF easiest. Effect of most inhibitors on soly. of $CaCO_3$ in acids not significant; soly. of $CaCO_3$ in cold HCl decreased noticeably by V and that in warm H_3PO_4 by I. Thus boiler scale can be safely dissolved at any temp. up to boiling provided proper inhibitor added to acid soln. At boiling temps. H_3PO_4 better avoided.—*C.A.*

Common Causes of Boiler Tube Failures. H. GLYDE GREGORY. Intern. Sugar J. (Br.) **47:** 45 ('45). Most frequent causes of boiler tube failures are bagging, blistering, or rupturing due to internal deposits which insulate tube metal from cooling medium, and corrosion due to oxygen or other components of feed and boiler water. In sugar mills greatest loss caused by outside corrosion during dead season. All soot should be removed from tubes and coat of preservative added after crop.—*C.A.*

Silica Deposition in Steam Turbines. F. G. STRAUB & H. A. GRABOWSKI. Combustion **16:** 7: 41 ('45). Lab. and power-plant tests conducted to det. cause of deposition of SiO_2

in steam turbines indicate that SiO_2 leaves boiler as vaporized silicic acid, which later crystallizes on blades in lower-pressure stages of turbine. When SiO_2 in steam below 0.1 ppm., no appreciable deposits found in turbines. Deposits can be prevented by maintg. SiO_2 in boiler water below 5 ppm. or removing SiO_2 from steam by scrubbing with pure water.—$C.A.$

Silica Removal From Water With Compounds of the Alkaline Earth Metals. WILLI UFER. Angew. Chem. (Ger.) **54**: 496 ('41).

Removal of silica from tap water with total hardness of 12–13.6° (Ger.) investigated with CaO. Before addn. of lime, carbonate hardness removed by boiling for 1 hr. All expts. performed in iron vessels. Samples filtered prior to pptn. of dissolved lime and then CO_2 passed into water to permanent phenolphthalein pink. Desilicification with quants. of CaO less than soly. dependent upon time at 100°. At 100°, 150 mg./l. CaO desilicifies after 10 min. to 1.6 mg./l. SiO_2, after 40 min. to 0.6. Desilicification is improved on adding amts. of CaO exceeding soly. Addn. of 4800 mg./l. at 30° leaves 0.2 mg. SiO_2 in soln. In presence of excess solid, CaO neutral salts and temp. have no influence on desilicification. Effectiveness of different lime samples proportional to their surface area. After treatment of limed water with 20 mg./l. $FeCl_3$ and 20 mg./l. $AlCl_3$ as flocculating agents clarifies soln. and desilicifies to 0.1 mg./l. SiO_2. That desilicification depends on adsorption as well as on pptn. of insol. Ca silicate shown by adsorption expt. with lime water (1.45 mg./l. CaO) which followed Freundlich adsorption law. With excess solid CaO, equil. concn., independent of initial amt., adjusts itself to 0.2 mg./l. Pptn. of dissolved lime also causes desilicification, e.g., from 1.0 mg./l. SiO_2 before pptn. to 0.5 after pptn. Same effect also occurs when lime is pptd. with $(NH_4)_2C_2O_4$.—$C.A.$

Water Treating. Corrosion Prevention by Vapor-Phase Treatment in Steam-Making Units Is One of the New Developments. C. E. ERB. Oil Gas J. **41**: 198 ('43).

Problems of treatment of water in oil refineries discussed. Treatment of water with β-glucoside or its derivatives prevented caustic embrittlement. Glucosate effective in removing oil from tubes of water tube boiler. Chrome glucosates prevented corrosion on oil side of condensers and in units using steam for processing. Inhibitors in aqueous soln. injected into steam have reduced corrosion in pipes carrying condensed steam. Methods for control of algae and bacteria and for prevention of scale formation discussed. Cupric chromoglucosate has proved useful for control of micro-organisms and for prevention of corrosion.—$W.P.R.$

Tube Pitting Traced to Unequal Water Flow. RALPH BRISCOE. Elec. World **119**: 443 (Feb. 6, '43).

Importance of proper feedwater distr. within boiler drum to provide uniform water quants. for circulation to all parts of boiler demonstrated. In boilers installed only 2 yr. previously, pitting occurred in front row tubes. No such evidence for 5- to 6-yr.-old boilers. Actual pressure under which water injected into drum and distributed is difference between boiler-line feed pressure and drum steam pressure. In this case, differential never exceeded 50 psi. With boiler out of service, therefore, simple to reproduce operating conditions. Boiler-feed line disconnected and reconnected to house service supply, about 80 psi. at this el. With orifice in line and boiler drum manhole doors removed, possible to observe and measure water flow and distr. along feed trough inside drum. As water led into 2 top outside drums, quant. equal to $\frac{1}{2}$ steam output introduced at all outputs. By varying water quant., observed distr. corresponding to various outputs in boiler. Revealed water quant. flowing from feed trough at one end greatly exceeded that from other over wide range. Corrosion or pitting confined to tubes in section where flow from feed trough least, i.e., end nearest inlet end of feed pipe and in tubes nearest fire. Little or no pitting occurred in portion securing large quants. of water. After capping end of 25′ feed pipe, $2\frac{1}{2}''$ diam., plugging some of $\frac{1}{2}''$ holes near outlet, alternate holes for first 4′, and every third hole for next 4′, pitting did not recur, even though water distr. along trough for all boiler outputs not perfect.—$Ralph\ E.$ $Noble.$

Fixing and Determining Oil in Feedwater and Boiler Water. C. A. NOLL & W. J. TOMLINSON. Ind. Eng. Chem.—Anal. Ed. **15**: 629 (Oct. '43).

Available methods for oil detn.: (a) std. method, involving extraction of residue on evapn. by petroleum ether; (b) tech. method, liquid-liquid extraction with chloroform; (c) ether extraction method, liquid-liquid extraction; (d) Am. Boiler Mfrs.

Assn. Method involving acidification and extraction with chloroform or ether, or low temp. concn. before extraction; and (e) Scott's method, in which oil adsorbed on ferric hydroxide floc and then extracted. Direct extraction methods err by including some inorg. salts in wt. of oil residue. Scott method fails to recover oil which has separated on walls of container during standing. Method described, modification of Scott method, fixes oil on floc at source of collection.—*A. A. Hirsch.*

Steam Contamination by Aquaglobejection. R. W. SENIFF. Bul. Am. Ry. Eng. Assn. 446: 57 (July '44). Research program started in '27 on Alton RR. to det. cause and remedy for boiler water carry-over. Equip. developed which can be used to differentiate between carry-over resulting from foam and moisture ejected into steam space from bursting of steam bubbles, which investigation has indicated to be of considerable importance in boiler operation. Author has termed this ejected moisture which carries boiler water salts as "aquaglobejection" to differentiate this from carry-over from foam. Larger particles, of sizes up to ¼-in. diam., called "micraglobes" and smaller, of fog or mist proportions "migroglobes." Photographs taken with this equip. show ejection definitely above water surface from bursting bubbles, of various particles of moisture from microscopic size to larger dimensions, based on qual. of water and size of bubbles. Layer of foam on surface, such as occurs when water of high concn. boiled, appears to retard moisture ejection, which explains why trouble has not been serious in locomotive boiler operation but may be contributing cause for turbine blade deposits with steam from h-p. boilers. Details of test equip. and photos of results given.—*R. C. Bardwell.*

Internal Feedwater Treatment of Locomotive Boilers. JEAN DE FRANK. Proc. Master Boilermakers Assn. 69 ('44). After description of possible reactions taking place in treatment of water with org. colloids, claim made that all-colloidal water treatment does not soften water or cause changes in chem. composition of impurities but, instead, helps to ppt. and renders them harmless by purely phys. process. Development work claimed to have been done at Riga, Latvia, but no specific data given for such treatment on railroads in U.S.—*R. C. Bardwell.*

Methods for Taking Water Samples. R. M. STIMMEL ET AL. Am. Ry. Eng. Assn. **46**: 448: 66 (Nov. '44). Progress report calls attention to precautions to be taken in obtaining representative water sample from locomotive boilers and avoid loss from "Flashing."—*R. C. Bardwell.*

Mechanics of Foaming and Carry-Over in Locomotive Boilers. WALTER LEAF ET AL. Am. Ry. Eng. Assn. **46**: 448: 59 (Nov. '44). Foam height found to be critical formation of vol. rate of steam evolution and for any vol. rate there is limiting foam height which does not depend on composition of dissolved solids. Calcite pptd. inside boiler or later added increases foam height beyond that from dissolved solids only if appreciable amt. of foam caused by dissolved solids, but max. foam that can be formed by any combination corresponds to limiting foam height caused by rate of evapn. $Mg(OH)_2$ first depresses foam height, later increases it and then gradually loses its stabilization power.—*R. C. Bardwell.*

Study of Treating Boiler Feedwater. C. A. HARPER ET AL. Proc. Master Boilermakers Assn. 63 ('44). Replies from 36 railroads to questionnaire developed that scale formation no longer problem with proper water treatment. Foaming and carry-over still matter of major concern and recommendation made to increase steam space in boilers to permit raising point of critical concn. and to control concn. by well-supervised blow-down schedule. —*R. C. Bardwell.*

Modern Treatment of Feedwater Using Wofatits (artificial-resin exchange materials). W. WESLY. Chem.-Ztg. (Ger.) **67**: 338 ('43). Methods of treating water for boiler feed may be divided into 2 classes: those depending on pptn. of substances to be removed from water and those depending on ion exchange. Disadvantages of former class of method discussed. Ion-exchange methods remove only electrolytes from water. Characteristics required in water to be used for boiler feed and methods for removal of suspended matter, oil, iron, manganese, bicarbonate, carbon dioxide, silica and sodium hydroxide described. Properties of synthetic resins (Wofatits) discussed. Synthetic resins capable of removing ions from soln. by reversible exchange process. Both cation- and anion-exchange materials condensation products of aromatic compds. of acid character, particularly phenols, with aro-

matic or aliphatic sulfo- or carboxylic acids, and with aldehydes, particularly formaldehyde. Anion-exchange materials condensation products of aromatic or aliphatic amines with aldehydes and related compds. Possible to produce cation-exchange materials which will remove carbonate but not non-carbonate hardness. Synthetic resins have large surface area and therefore high rate of exchange, and great mech. stability. Filter medium can be fairly coarse. Resins do not yield to water being filtered any silica or org. matter. Suspended matter must be removed from water which is to be filtered through synthetic resins. Type of resin suitable for treating hot water not necessarily suitable for cold water. Cation-exchange materials generally used in form of sodium salts; cations in water taken up by resin which liberates sodium ions. When resin exhausted, regenerated with sodium chloride. Specific load, that is, vol. of water treated (in cm./hr.) divided by vol. of resin (in cm.) varies with different cation-exchange materials between 10 and 25. Exchange capac. expressed as wt. of ions absorbed (expressed as kg. of calcium oxide) by 100 l. of resin. Wofatit P in large-scale operation has shown exchange capac. of 1.0 to 1.1; it has been used satisfactorily to treat water at temp. of 95°C. and with pH value of 8.5, and has not been adversely affected by boiler water with pH value of 10.6 and temp. of 95°C. Stability of Wofatit P to heat makes it particularly suitable for softening condensate. Salt soln. used for regeneration of cation-exchange resins should be clear and should be as free as possible from hardness-forming salts. Temp. of salt soln. should be about same as that of water to be treated to prevent fluctuations of temp. in filter. To displace salt soln. after regeneration, softened or raw water may be used; recently boiler water, which has been cooled and from which sludge has been removed, has been used. Hardness in water softened by Wofatit resins 0.05° (Ger.) or less. Wofatits P and KS will soften water which contains much sodium chloride. For complete removal of salts cation-exchange materials used in form of acids. If Wofatit used in which acid stronger than mineral acids in water all cations in water replaced by hydrogen and filter effluent contains carbonic acid and other mineral acids. If this effluent now flows through anion-exchange material, all acids except carbonic acid removed. Carbonic acid must be subsequently removed. Specific load for complete removal of salts about 10.

Cation-exchange material regenerated with soln. contg. 50 to 70 g. of hydrochloric acid per l.; amt. of hydrochloric acid required varies between 180 and 230% of calcd. amt., that is, between about 24 and 30 g. per deg. (Ger.) of hardness removed per cm. of filter medium. Anion-exchange material regenerated with soln. contg. not more than 20 g. of sodium hydroxide or 100 g. of sodium carbonate per l. Amt. of alkali required up to 200% of calcd. amt. Freshly regenerated anion-exchange material releases some alkali into treated water; when resin becoming exhausted small amts. of hydrochloric acid appear in water. Fluctuations in pH value due to these compds. can be avoided by subsequent filtration of water through buffer filter, which is usually cation-exchange material. At first this filter takes up sodium ions and releases hydrogen ions; later opposite reaction occurs. Filter therefore automatically regenerated and pH value of water remains practically const. Removal of salts from water contg. much sodium chloride usually achieved by filtration through 2 filters in series. Divalent ions more readily removed than monovalent ions. Wofatit P and Wofatit M used for treating hot water. Compn. of water to be treated affects type of prelim. treatment given, choice of Wofatit, and size, number and arrangement of Wofatit filters. If desired to remove carbon dioxide and hardness-forming compds. but not all cations, water divided into 2 parts. One part filtered through hydrogen-exchange material, and other through sodium-exchange material. Proportions of 2 parts so adjusted that acids in one part just sufficient to neutralize sodium bicarbonate in other part. After neutralization free carbon dioxide removed. In another method for partial removal of salts, water first filtered through hydrogen-exchange material in which acid not sufficiently strong to decompose non-carbonate hardness but which decomposes carbonates. If filter effluent contains small amts. of mineral acids passed through buffer filter contg. cation-exchange material such as Wofatit C; this removes mineral acids and non-carbonate hardness but not carbonic acid. Effluent contains sodium salts instead of non-carbonate hardness and free carbon dioxide instead of carbonate hardness. Complete removal of carbon dioxide and oxygen from water can be achieved only by chem. methods. Carbon dioxide formed in boilers by decompn. of sodium carbonate neutralized by addn. of ammonium salts,

which give condensate pH value above 9 and make it non-corrosive. 3 examples given of treatment of feedwater for boilers operating at pressure of 120 atm. In first example, raw water is well water contg., in mg./l., total solids 220 to 290; sulfate 40 to 60; chloride 25 to 45; silica 8 to 12; and having carbonate hardness of 6° to 8° (Ger.); non-carbonate hardness of 2.2° to 4.5° (Ger.); and potassium permanganate demand of 6 to 9 mg./l. Water heated to 97°C. and treated with 200 g. of calcined dolomite per cm. in mixing tanks with period of retention of 4 min. before flowing to sedimentation tank with period of retention of 2 hr. Water next pumped through Magno filter, and, after addn. of sulfur dioxide to remove oxygen, passed through Wofatit filter. Mixt. of ammonium sulfate and diammonium phosphate added to feedwater, which contains, in mg./l., total solids 160 to 200, silica 0.25, and combined carbon dioxide 8 to 11 (expressed as sodium bicarbonate). Contains no oxygen and has hardness of 0.015° (Ger.). Wofatit regenerated with dil. soln. of sodium chloride at temp. of 75°C. Hardness removed by 100 l. of Wofatit equivalent to 1.13 kg. of calcium oxide. No deposits have formed on turbines. In second example boiler operates on condensate to which added up to 30% of chemically treated water. Raw water contains, in

mg./l., chloride 30 to 40, sulfate 60, and silica 11 to 12; has carbonate hardness of 1.0° to 1.5° (Ger.), total hardness of 5° to 7° (Ger.), magnesium hardness of 2° (Ger.), and potassium permanganate demand of 40 to 100 mg./l. Treatment carried out in cold. Sodium aluminate and magnesium chloride added to raw water. Mixing tank and sedimentation tank together have period of retention of 2 hr. Water next passed through Magno filters, Wofatit KS filters and Wofatit P filter. Finally oxygen removed first by heating and then by treatment with sodium sulfite. Feedwater contains 0.3 mg. of silica per l. and has hardness of 0.02° (Ger.). In third example raw water same as in second. To raw water is added 40 g. of ferric chloride per l.; water next filtered through gravel filters without being allowed to settle. Then filtered through cation- and anion-exchange materials and through buffer filter. Oxygen removed by heating water to 103°C. and by addn. of sodium sulfite. Treated water contains no sulfate, 3 to 7 mg. of chloride per l., and 9 mg. of silica per l., and has hardness of 0.02° (Ger.) and potassium permanganate demand of 10 to 20 mg./l. Make-up water amts. to 10% of boiler water, so that concn. of silica in boiler only 0.9 mg./l. Operation has been satisfactory over period of 18 mo.—*W.P.R.*

CHEMICAL FEEDING, CONDITIONING AND SEDIMENTATION

The Development of Emergency Equipment at Montebello. A. A. BAILEY. Proc. Md.-Del. W. & Sew. Assn. p. 51 ('44). *Alum soln. control:* Original alum soln. controllers consisted of const. level tank with adjustable orifice at bottom. Const. level controlled by balanced piston valve operated by float. These valves so large in comparison with quant. of soln. passing through them that small objects, such as match sticks, would wedge themselves between seat and disc and prevent them from shutting off properly. Valves recently replaced by pinch valve arrangement, consisting of piece of 2½" pure gum hose, 8" long, clamped to inlet pipe and pinch arm operated by float. Outlet in bottom of controller consisted of bronze ring bolted to c-i. base and cylinder having irregular-shaped slot cut in one side forming orifice. Cylinder could be raised and lowered through ring to give necessary rate of flow (Fig. 1). Combined chem. action of alum

and abrasive material carried in soln., cut into surface both of cylinder and ring, so that in very short time after new outfit installed, would be necessary to set back on opening to secure proper quant. Also, impinging of soln. on side opposite orifice slot would soon cut through cylinder. Thickening of wall at this point helped to increase life of cylinder. Because of these difficulties decided to try new arrangement. Original controller lead lined and used simply as const. level tank and soln. piped to new controller orifice. Controller consists of short lead cylinder 4" in diam. with hard rubber nozzle and plug with bronze stem. Held in place by framework in which it is free to slide in order to secure proper elevation. Orifice adjustment made by means of knarled nut on stem held in place by framework supporting indicator and dial. Dial marked in percentage of capac. If indication had been made to show percentage of capac. by direct reading of movement of stem
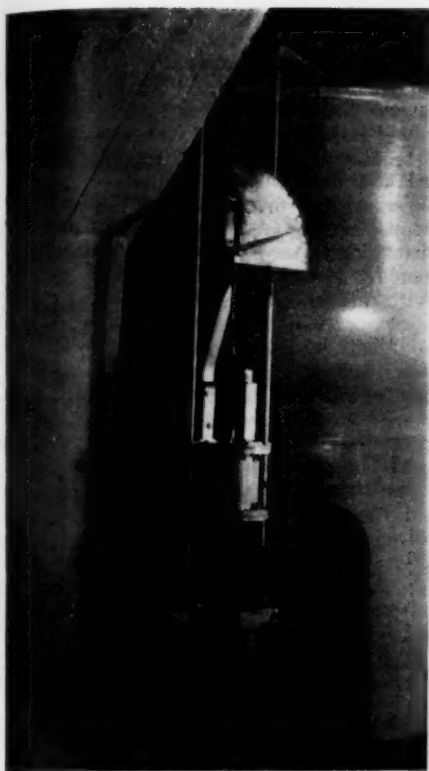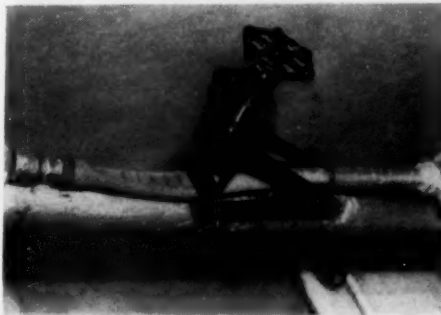
FIG. 1.   Alum Controller
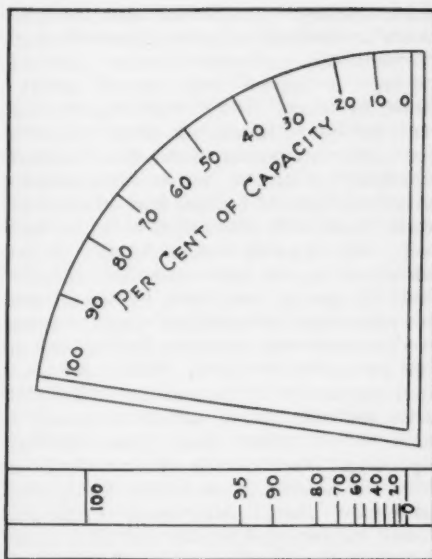
FIG. 2.   Alum Controller-Indicator

percentages between 20 and 50 would be so close together would be impossible to read them accurately.   In order to get even spacing on dial and large enough spacing to read easily, arrangement made as shown in Fig. 2. Pin in end of arm attached to stem slides in slot in pointer.   This makes movement of pointer greatest when stem movement is least and smallest when stem movement is greatest, giving nearly even spacing on dial.   Original idea was to have 2 methods of regulation, one by changing elevation of nozzle, thereby changing head, and other by changing orifice opening.   Satisfactory results obtained by keeping head const. and varying nozzle opening only.   Now operating with 3'9" head above nozzle opening which gives max. output of 40 gpm.   Soln. not taken from extreme bottom of controller but from point about 20" above bottom, elimg. much of heavy sludge. Valve provided at bottom of cone-shaped controller to flush out sludge.   After 16 yr.

of service of one of these nozzles no appreciable wear on any rubber or lead parts.   Only parts that have had to be replaced are bronze stem and bronze tip on rubber plug.   *Lime soln. controller:* Lime soln. hard to control accurately due to clogging of orifice openings, especially during low flows.   Best arrangement for handling this material is with simple pinch valve made of piece of rubber hose, preferably sandblast hose, which, while soft, has enough rigidity to hold its shape even under suction (Fig. 3).   Two of these outfits in use at present time.   In one, control accomplished by cam pressing against swinging plate which in turn flattens hose to secure

FIG. 3.   Lime Controller

desired opening. Arm, which operates cam, clamps to quadrant to maint. desired setting. Quadrant also graduated to show degs. of opening. In second case, control accomplished by use of old 2½″ valve bonnet and stem, welded to framework which supports hose. Bar that presses against hose fastened to inner end of stem so that stem free to turn. Gives better control because finer adjustment can be made with screw than with cam and lever. Any clogging that might occur in restricted section of hose easily and quickly elimd. by opening valve wide for second and then returning it to its original setting. Lime does not have same tendency to build up on hose as on metal parts. With even less attention control as accurate as with metal valves and only critical material necessary is about 10″ of rubber hose. *Sand washing:* Experienced much trouble with mud balls in filters and washing with Nichols equip. did not remove them. After sand completely washed and returned to filter and filter backwashed, top several in. of sand contained innumerable mud balls, approx. size of peas. These very soft and by running sand through two ejectors instead of one, mud balls could be completely removed. To accomplish double ejection before sand entered separator, welded extra high section on top of std. ejector hopper. One side of extension 2″

lower than other three and bent over to form overflow from hopper. Necessary because impossible for second ejector (see Fig. 4), same size as first, to carry combined output of first ejector plus its own water. Trough with 3″ outlet at one end attached under this overflow and piece of 3″ downspouting carries overflow waste to wash trough. Trouble experienced at first with air drawn into first hopper causing great amt. of boiling up and spattering in second hopper. Overcome by hanging series of baffles in second hopper. With this arrangement sand discharged from separator completely cleaned and free from mud balls. *Handling wet copperas:* Until few years ago dry ferrous sulfate purchased in carload lots and stored in bins. In last few years wet copperas purchased locally at much lower cost. Originally this material dissolved by placing it in tank which had spray pipes in bottom. Water from spray pipes aided by occasional stirring with shovels, dissolved copperas and soln. run into soln. tank. Wet copperas delivered in drums contg. about 200 lb. Drums raised by elec. hoist and dumped into dissolving tank. Next built concrete hopper with ejector in bottom. Drums handled in same way as before and dumped into hopper. Spray pipes around top washed copperas down and ejector forced mixt. out and through 25′ length of 3″ hose
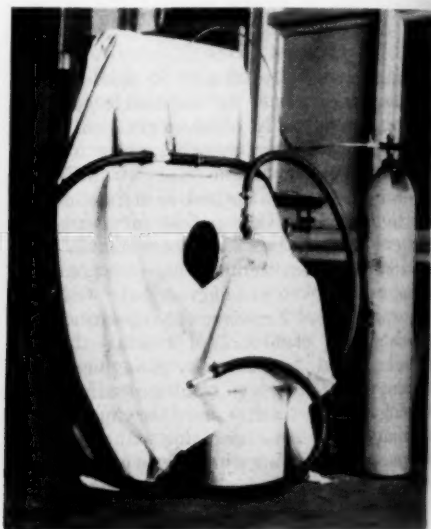

FIG. 4. Second Sand Ejector

FIG. 5. Portable Emergency Chlorinator

to soln. tank. When copperas reached soln. tank completely dissolved. This work done on second floor of chem. bldg., necessitating considerable handling of drums. To lessen work and elim. much of mess due to leaky drums and careless handling, decided to put dissolving equip. in basement. Shute built through large window, down which copperas dumped directly from truck. Wooden platform built under shute and from this copperas shoveled into hopper ejector similar to Nichols sand ejector. Hopper and ejector made of bronze which holds up very well under action of copperas. Mixt. of water and copperas passes through hose to small tank and from this tank pumped by Duriron pump to soln. tanks. With this method of handling any mess that might occur can be easily flushed down basement drain and mixing room can be kept dry and clean. If dry material used shoveling would be elimd. as it could be run directly from storage bin into hopper, but in case of wet material, this cannot be done.
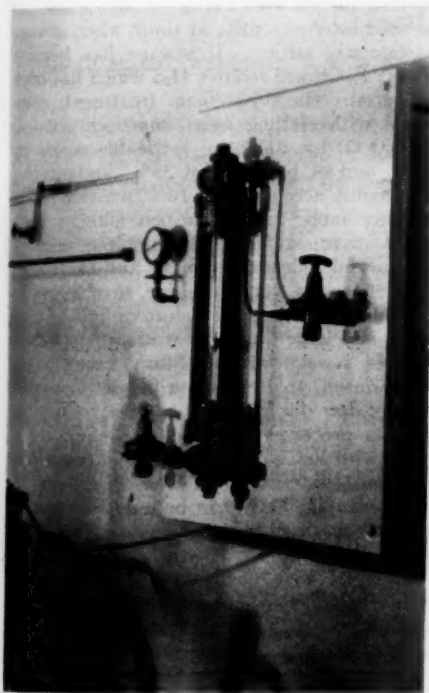
Fig. 6. Chlorinator—2000-lb./Day Capacity

Possible to dissolve and deliver to soln tanks from 6½ to 8½ tons of copperas per hr., depending on its condition. *Chlorinators:* 2 types of chlorinators for emergency use, one a portable outfit for use in chlorination of mains, other used in Montebello plant to supplement regular equip. in handling large quants. of chlorine until central chlorinator station built with up-to-date equip. 16 portable outfits, built at beginning of war with idea of chlorinating mains after bombing raid. Very simple in design, consisting only of hard rubber ejector, necessary hose for handling pressure water and chlorine soln., soln. tube and copper tube to connect ejector to chlorine cylinder. Soln. tube made from piece of $\frac{7}{8}''$ od. copper tubing, lined with piece of $\frac{3}{32}''$ wall rubber tubing $\frac{1}{4}''$ id. Rubber tubing pulled through copper tube and about 2'' on end folded back on outside of copper tube, over which soln. hose clamped (Fig. 5). So far, this soln. tube has proved very satisfactory for emergency use and could be used to replace std. silver tube on permanent installations in case of necessity until new one could be secured. Entire outfit can be made for about $50, including labor and material. After war plan to build central chlorinator station which will supply post-chlorination to water before it is divided between two filtration plants. With increased demand for water during last few years, and fact that rate of chlorination greatly increased, became necessary to add to chlorinating equip. Rather than purchase extra equip., which probably would not be satisfactory for future development, decided to build 2 emergency outfits to carry over until new program could materialize. These outfits use ordinary line regulator, mfd. by Alexander Milburn, from which seat and disc have been removed and silver parts substituted. Rate of flow of gas can be controlled by varying pressure through this regulator. Quant. measured by Schutte-Koerting rotometer. Second Milburn regulator connected to outlet of rotometer to act as back-pressure valve. From this gas piped to hard rubber ejector and from thence to water. One of these outfits has capac. of 1200 lb. per day and other has capac. of 2000 lb. per day (Fig. 6). Have proved very satisfactory for manually-operated machine where control does not have to be perfect. Cost of building one of these units approx. $150, including labor and material.—*Ed.*

The "Flexiflow" Automatic Chemical Doser. ANON. Wtr. & Wtr. Eng. (Br.) **48**: 145 (Mar. '45). Unifilters "Flexiflo" chemical doser effects rate of admin. of chems. so that it keeps in step with flow being treated. Operated by water pressure. Diaphragm controlling element connected across Venturi tube fitted in main at point where treatment is desired. Differential pressure causes diaphragm to pulsate with frequency in direct ratio to rate of flow through Venturi tube. Valve gear supplies operating water to one or more diaphragm-type chem. pumps so that their movement is synchronized with that of motive unit. Normal range of these machines has been designed to give 8 : 1 ratio. Larger or smaller ratios can be dealt with. Three sizes of units have been designed: 5, 15 and 45 gal. (Imp.) per hr. These chem. dosing sets have been supplied to Army for mobile sterilization units.—*H. E. Babbitt.*

Chemical-Mechanical Treatment of Water With FeCl₃. A. K. MEHNER. Chem. Tech. (Ger.) **15**: 129 ('42). Use of FeCl₃ in purif. of water, sewage and trade-waste waters discussed. Solns. of FeCl₃ varying in strength from 50 to 400 g./l. used. Dose required varies with each water; as small a dose as possible should be added to avoid unnecessary costs and formation of bulky sludge, but below certain concn. pptn. slow and incomplete. This coagulant will remain in treated water if too little has been added or if too little alkali present; when FeCl₃ used, this is readily detected by yellow color of water. Adequate mixing of FeCl₃ with water essential, either by baffles, aeration or stirring. Floc removed by settling, with or without final nitration, or by direct filtration through coarse and fine filters in series. FeCl₃ added to water coagulates fine suspended and colloidal matter and removes color, org. Fe and Mn compds., H₂S, sulfides, NH₃, silica, oil, algae and bacteria. In aq. soln. FeCl₃ dissociates into ferric, hydroxyl, H and chloride ions. HCl produced neutralized by Ca-(HCO₃)₂ in water or by added alkali, and flocs of gelatinous Fe(OH)₃ formed. Content of chloride in treated water increased, but this does little harm. Fe(OH)₃ floc has very large surface and adsorbs fine suspended matter. Pos. ferric ions neutralize negative charge on colloidal matter which is then adsorbed on floc. Up to limit, increasing quants. of suspended matter make water easier to treat. Sulfides form Fe₂S₃, and if they are present in any quant. precautions must be taken to prevent their remaining in colloidal state. Eff. of coagulation by FeCl₃ only slightly decreased at low temps., and improved at high temps. Coagulation effective over relatively wide range of pH values. In acid waters, addn. of alkali necessary to insure pptn., and in very alk. waters coagulant can be saved by adding acid to neutralize some of alkali. Special uses of FeCl₃ discussed. Owing to increasing demand for drinking water, surface waters and ground waters of inferior qual. have had to be used. These waters must be treated for removal of color, turbidity, Fe, Mn, org. matter, H₂S, tastes and odors and bacteria. All removed by treatment with FeCl₃. Process also suitable for treating indus. water supplies, including boiler feedwater. Up to present, chem.-mech. treatment of sewage with FeCl₃ has been little investigated. Amt. of solid matter removed by settling can be greatly increased by coagulation with FeCl₃. Coagulation can be used intermittently, at times when sewage particularly strong. If sewage has become septic, FeCl₃ will remove H₂S which has been produced. On avg., chem. treatment, compared with settling only, improves removal of B.O.D. by 100%, of settleable solids by 57%, and of bacteria by 33%, and process also highly accelerated. Biol. treatment will produce more highly purified effluent than mech. treatment, but trickling filters produce odors and encourage flies, and activated sludge process very sensitive to changes in compn. of sewage, so therefore cannot be used when any large quant. of trade-waste waters reaches sewage works. Many cases where chem.-mech. treatment purifies sewage sufficiently for discharge to stream. Costs of various processes compared. Prelim. treatment with FeCl₃ can be used to improve performance of overloaded biol. sewage-treatment plants. FeCl₃ can be used for treating many types of trade-waste waters, either alone or in admixt. with sewage. Sludge from pptn. with FeCl₃ digests more rapidly than sludge from simple sedimentation and though vol. of sludge greater, digestion tanks of greater capac. not required; compn. of sludge gas not affected. Sludge contg. FeCl₃ suitable for use as fertilizer and readily dewatered on vacuum filters.—*C.A.*